Assessment of gas pipe reuse for termonet in Rårup

Project Report

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Declaration of authorship

"I hereby declare that my project group and I prepared this project report and that all sources of information have been duly acknowledged".

Bendegúz Boáz Balázs – 01.05.2023

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Glossary

BHE - Borehole heat exchanger

COP - Coefficient of performance

DW - Drinking water

FLEQ - Full load equivalent running hours

GSHP - Ground source heat pump

HHE - Horizontal heat exchanger

HP - Heat pump

IPA - Isopropyl alcohol

LER - Ledningsejerregistret

Ø - Diameter

PE - Polyethylene

PN - Pressure nominal

Re - Reynolds number

SCATER - SCreening Aid for Termonet Energy Renewable

SDR - Standard dimension ratio

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Summary

The main purpose of the report was to assess the possibility of reusing the existing gas network in Rårup. It was decided to phase out gas and heating oil, to become less dependent on imported gas and change to renewable energy. The low temperature ground source heating solution termonet was chosen as the most feasible solution to replace the existing heat supply. Hence, the currently used gas network becomes obsolete. It was recognized that gas pipe and termonet pipe material is the same and there could be an opportunity to utilize them. Also, the location of Rårup was favorable since the village is at the end branch of the gas network.

The design of the termonet was done using SCATER software, to analyze the compatibility of pipe diameters. The output of the simulations were pipe diameters for predefined sections, which then were compared to the diameters of the existing gas network.

It was found that it is possible to deliver heat to the village Rårup solely by termonet, where around 2.2 km (~44 %) of the gas network can be reused leading to cost savings in construction of around 975 000 – 1 160 000 DKK. This result can be further improved if higher pressure gradients are accepted in the network, as further described in this report. The needed length of the Horizontal Heat Exchanger in Rårup was determined to have a total length of 44.3 kilometers.

Regarding more termonet projects upcoming in the future, it is an important finding that reutilizing the gas network might save resources for the project and it is always worth investigating whether existing infrastructure can be reused.

It must be mentioned that no prior research on the topic has been published and there is no possibility to compare findings.

1 Introduction

1.1 Background description

According to the Intergovernmental Panel on Climate Change (IPCC), global warming will reach 1.4 to 4.4 degrees Celsius before 2100. This is quite a range, as science does not know how climate action will be implemented and manmade greenhouse gas emissions will develop in future (Eckert, 2022). The newest IPCC report however, states that global warming already reached 1.1 °C to date giving dismal outlooks on the further climate development.

To mitigate climate change to 1.5 °C as it was agreed on the Paris Agreement, greenhouse gas emissions must drop dramatically. The key point to do this is phasing out fossil fuels and switching to renewable energy sources, leading to a massive transition in the energy sector (IPCC, 2023).

Furthermore, the Russian war against Ukraine even accelerates the energy transition as Denmark urgently wants to become independent on Russian gas (Statsministeriet, 2022).

Hence, new heating sources are needed both for areas with and without district heating. For areas without existing district heating network, the ground source heat pump system termonet could be a potential heating solution. Termonet utilizes ground heat as primary input for individual heat pumps at consumers. The heat is gained by uninsulated distribution- and heat exchanger pipes in the ground (Termonet Danmark, n.d.). As gas pipes become obsolete in future, they could potentially be reused for termonet.

In this semester project report, the possibility of reusing gas pipes for termonet is investigated. The research is based on an example in Rårup, Denmark, where a termonet is planned to substitute the existing heating system which is mainly based on gas. Figures 1 and 2 show the location of Rårup.

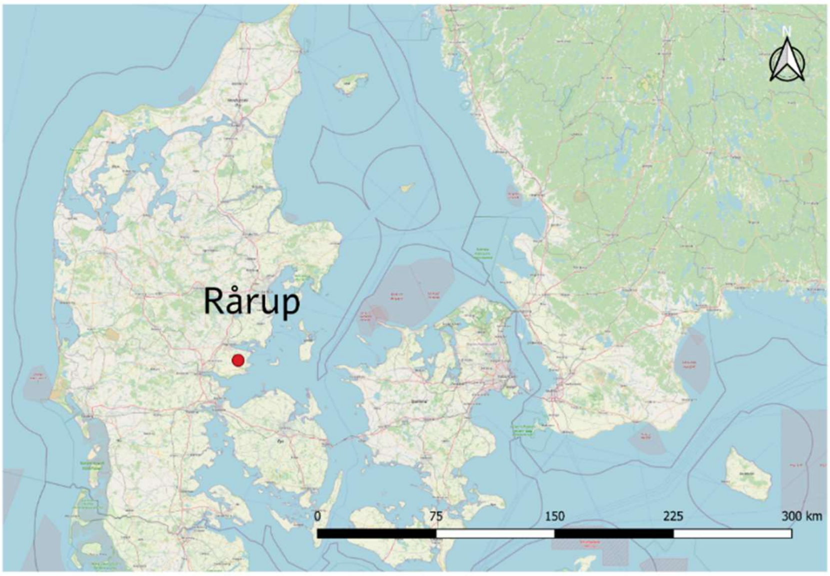

Figure 1: Location of Rårup

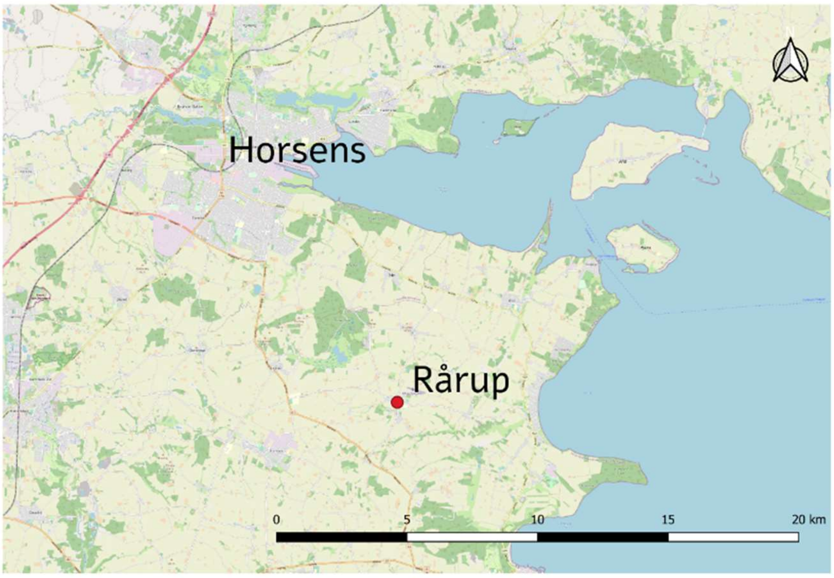

Figure 2: Location of Rårup

1.2 Definition of purpose

Denmark has a vast gas network which is on the path to become obsolete. As the gas pipes are made from potentially suitable material and are already installed on site, they might be suitable for being repurposed in termonet systems.
The purpose of the project is to investigate if soon-to-be-phased-out gas pipes can be used in a sustainable way by implementing new, climate friendly energy systems.

1.3 Problem statement

The main question that the report is going to assess is:
Can the existing gas network in Rårup be reused for termonet?

To answer the main question, the following sub questions below need to be answered:
How would the design of a termonet in Rårup look like?

- What are the boundary conditions for the termonet in Rårup?
- How can the termonet be dimensioned?

Is it technically possible to reuse gas pipes as waterborne pipes for the termonet?

- Do the existing gas pipes match the needed dimensions for termonet?
- Would the gas pipes comply with the safety distance to the existing pipes when they are used as termonet pipes?
- Can the existing gas network installation conform to the requirements of a liquid-based system?

Is it financially viable to reuse the gas pipes for the planned termonet?

- To what extend could the initial investment costs be lowered by reusing the gas network?

1.4 Delimitation

The following topics will not be considered in this semester project:

- Soil sample analysis
- Construction and delivery phase
- Logistics of switching the pipe network
- Cooling demand for the buildings
- User installations
- Environmental impact assessment

The supply area will be limited to the area that is currently covered by the gas network in Rårup, between the pumping station near Kirkedalsvej and the end of the network. At the same time the project is limited to the primary side of the network and ends at the consumers' house installations.

2 Theory/literature survey

2.1 Screening by NIRAS

The engineering consultant NIRAS made a heat supply screening of Rårup to determine the best heating solution for the village. In the screening three different heating solutions were compared: Individual heat-pumps, district heating and termonet. NIRAS concluded that termonet would be the cheapest solution and this was the basis for the decision of the citizens of Rårup in a community vote to choose termonet as their future heating method. The screening was performed with standard and experience values for termonet. Some of the parameters used in the screening and some of the financial findings were used to compare the simulations and calculations performed in this report (NIRAS, 2023).

2.2 Termonet

Termonet is a renewable heating solution primarily used in rural areas, where it is not financially viable to establish district heating due to lower consumption density. Consumers in these rural areas often have fossil fuel-based boilers, which must be replaced in the near future. Possible clean energy choices for the consumers are air-to-air heat pumps and ground source heat pumps. Air-to-air heat pumps is the solution with the lowest initial investment, but their efficiency drops significantly during the coldest winter days when heating is most needed, and they contribute to noise pollution. Ground source heat pumps have a stable performance during the different seasons, but need a substantial initial investment which often cannot be justified in rural areas, where the value of houses is comparably low.

Termonet is a ground source heat pump system, that builds on the historical Danish spirit of having local cooperatives. The large initial costs and the resulting risks of creating the ground source system are split between the participants. It has low operational costs and is therefore a good long-term investment in the local communities.

When compared with traditional district heating, the main difference is that heat is gained in the entire network and not produced centrally at one plant. The low operating temperatures makes it possible to utilize multiple low temperature heat sources, such as horizontal heat exchangers, boreholes, and low temperature waste heat. The energy is transported to the consumers via waterborne pipes, which are filled with a mixture of water and anti-freeze. The temperature of this brine in the supply line is close to the soil temperature and needs to be lifted to the end-temperature by an individual heat pump at each consumer.

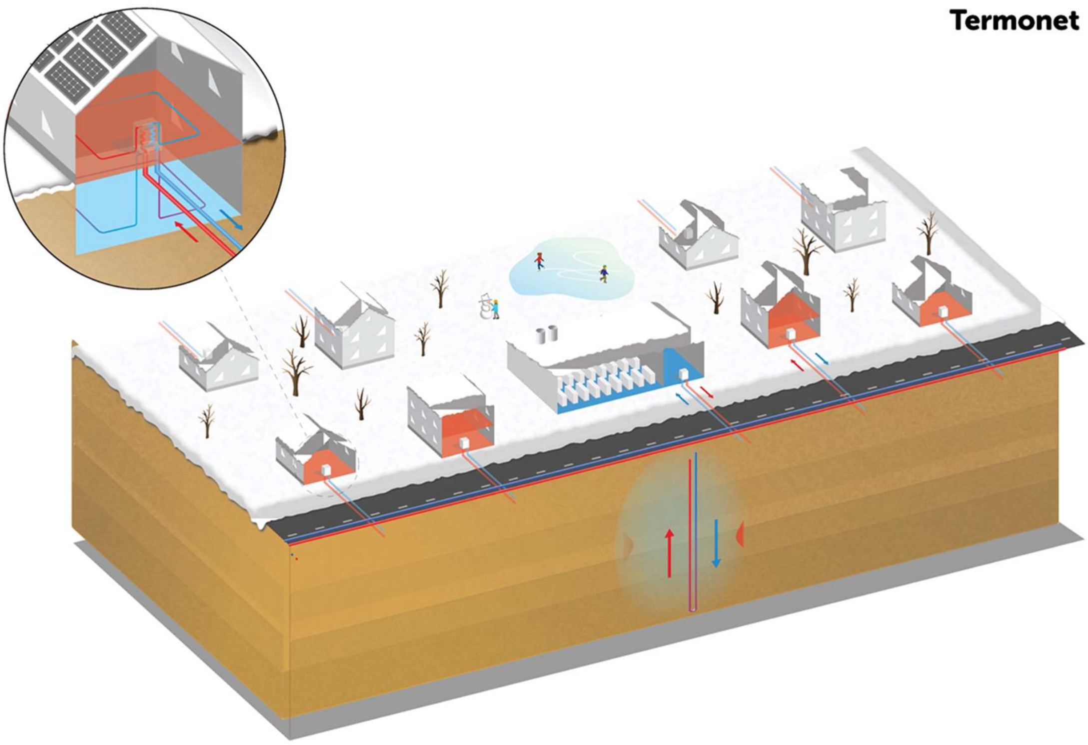

Figure 3: Cross section of a termonet design (Termonet Danmark, 2023)

The termonet system can also provide cooling by reversing the circulation cycle at the consumer end and utilizing the constant low temperatures in the return cycle. When the system operates in cooling mode it transfers heat back into the soil and can hereby recharge boreholes.

The water circulation in the supply and return pipes is provided by the circulation pump of the individual heat pumps. If this is not sufficient, a booster pump can be added to the system, but this would need additional investment.

2.2.1 Termonet pipes

Due to the low temperature in the termonet, uninsulated plastic pipes are used, unlike in traditional district heating, where pre-insulated pipes are utilized (see figure 4). The uninsulated plastic pipes have the advantage that they lower the initial investment significantly (Tommy Olsen, 2021). In addition to the primary heat source in the termonet (Horizontal heat exchanger, boreholes, waste heat etc.), the distribution network also gains heat from the ground, which normally can provide around 30 % of the energy in the system (Poulsen, 2023).

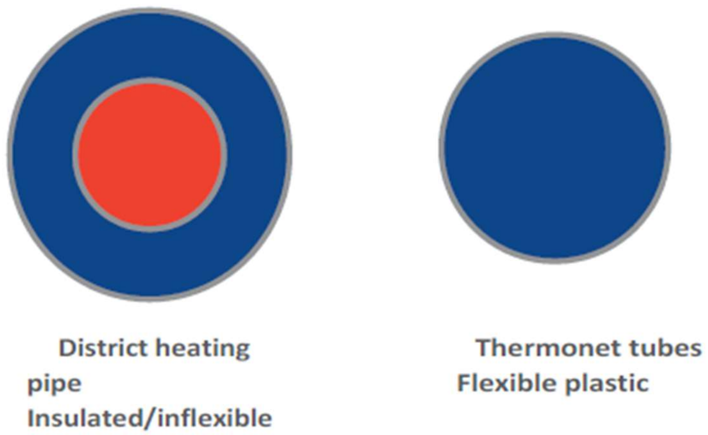

Figure 4: District heating pipe comparison to termonet pipe (Tommy Olsen, 2021)

According to the Danish "Bekendtgørelse om jordvarmeanlæg" §14 stk 1 the pipes used in a ground source heating setup should be either PE40 SDR11 or PE80 SDR17. The pipes should comply with the standard "EN 12201" and the pipe network must have a minimum pressure of 150 kPa. (Retsinformation, 2017).

2.2.2 Horizontal Heat Exchanger

Horizontal pipe heat exchangers (HHE) are used in ground source heating systems. A HHE consists of buried pipes typically at depths around 1-3 m, through which a heat carrier fluid circulates. While in circulation, the fluid absorbs the heat energy from the ground and transfers it to the heat pump at the consumer. When using reversible heat pumps, the process may be reversed, and the ground can be used for cooling instead.

Typically, horizontal heat exchangers require more land area than borehole heat exchangers. They can be a cost-effective solution when the required land area is available. As the HHE is a very shallow geothermal heat source, it is influenced by the seasonal variation of the solar radiation. (Yu Shi, 2022)

2.3 Gas pipes

The main scope of the project is to analyze the possibility of using gas distribution pipes for termonet. To determine the potential application of the pipes, it is necessary to analyze the type of material gas pipes are made of and the compatibility with the pipes used in termonet. Additionally, since the gas pipes in the project area were installed in the late 1980s (Schmidt, 2023), their remaining lifetime must be taken into consideration.

2.3.1 Material and specifications

The material of the pipes together with their respective data sheets were provided by Evida. From the data provided most of the pipes are of the plastic PE80 type, while a couple of sections being plastic PE100. The pressure class is listed as PN2.5 for PE80 and PN4 for PE100 pipes and the SDR was calculated to be 17. From the manufacturers catalogue “Wavin håndbog” further information can be found regarding the laying instructions for gas pipes.

It is stated that the filling material and the material in the gas pipe bed must have a maximum grain size of 20 mm for uncrushed and 8 mm for crushed material. Pipes in the ground must have at least 1 m of cover; under the roads in residential areas at least 0.8 m; and under the green areas/gardens/bicycle and pedestrian paths at least 0.6 m. Pipes with diameters greater than 160 mm without protective cover must always have a distance of at least 1 m (Wavin, 2021). On the figure 5 below a sketch of the pipe placed in the pit can be seen.

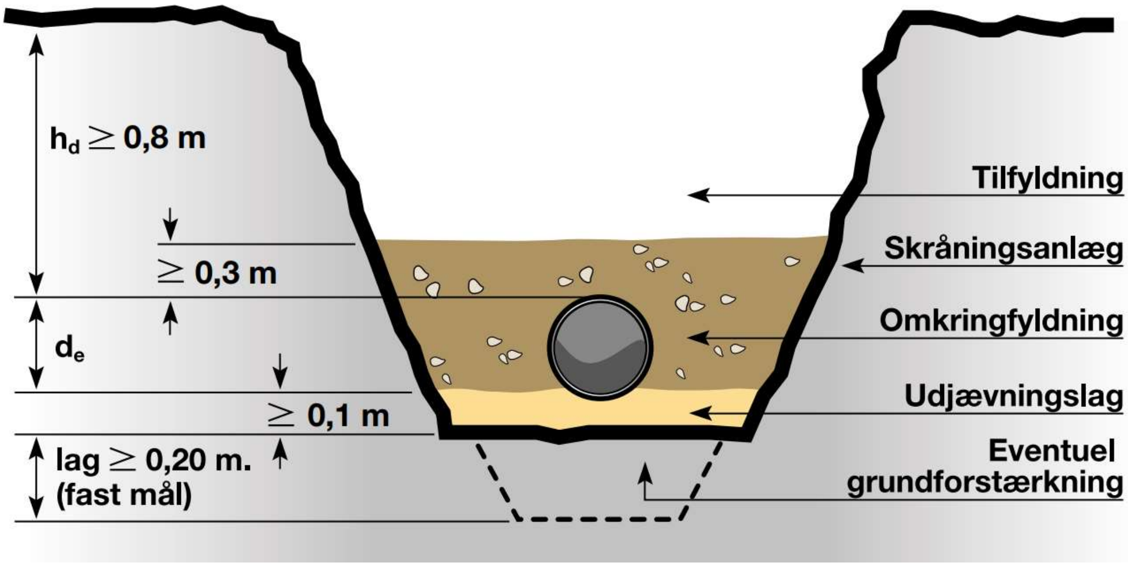

Figure 5: Sketch of the pipe placement for PE80 and PE100 pipes. (Wavin, 2021)

2.3.2 Life cycle

The gas distribution network in Rårup was established in 1988 meaning that the age of the oldest pipes in the network at the time of writing this report is 35 years (Schmidt, 2023). The periodical issue "GASenergi" nr. 3 from 2016 by Dansk Gas Foregning published an article "Levetidsvurdering af PE-nettet: De danske gasrør kan holde mindst 50 år endnu". As of 2016, the Danish natural gas network consisted of approximately 19 000 km of pipelines, of which 15 500 km were the PE type. At the time of publishing the article, most parts of the pipelines were nearing the age of 25-30 years. It was found relevant to look at the condition of the PE network. The article presented the methods and results of extensive pipe testing that was carried out by Wavin and accredited by Danish Technological Institute.

A total of 22 pieces of gas pipes were dug up all around Denmark. The tests were carried out according to the standard DS/EN 1555 and DS 2131-2. These are the requirements that were placed on newly produced pipes. If the pipes meet the requirements, the lifetime is defined as 50 years. To ensure a comprehensive selection in the lineup, a wide selection of dimensions, age and materials was covered. The pipes tested were between

7 and 34 years old, meaning that several pipes were produced according to an old standard. Table 1 below shows the pipes used in the test:

Pipe	Ø in mm	Pressure class	Type	Age [y]	Manufacturer
A	20	PN 4	PEM	15	Wavin
B	20	PN 4	PEM	29	Uponor
C	25	PN 4	PEM	34	Wavin
D	20	PN 4	PEM	28	Wavin
E	63	PN 4	PEM	26	Uponor
F	63	PN 4	PEM	23	Wavin
G	63	PN 2.5	PEM	34	Wavin
H	63	SDR 11	PE 100	11	Uponor
I	63	SDR 11	PE 100	12	Uponor
J	20	PN 4	PEM	27	Uponor
K	63	SDR 11	PE 100	12	Uponor
L	63	SDR 11	PE 100	11	Uponor
M	63	PN 4	PEM	27	Uponor
N	63	SDR 11	PE 100	7	Uponor
O*	90	PN 4	PEM	26	Uponor
P	125	PN 4	PEM	31	Uponor
Q*	125	PN 2.5	PEM	31	Uponor
R	125	PN 4	PEM	17	Tarco
S	125	SDR 11	PE 100	10	Uponor
T	125	SDR 17	PE 100	11	Uponor
U	125	PN 4	PEM	30	Wavin
V*	160	PN 2.5	PEM	26	Wavin

Table 1: The division of pipes used in the tests

**Indicates that pipe had been used for raw biogas or landfill gas*

The tests investigated if the pipes have been ovalized and if the diameter is as stated. Additionally, the toughness and strength of the pipes were tested, just as it is tested for welding. The strength was tested by subjecting the piece of pipe to accelerated ageing by pressurizing the pipe with water and immersing it in hot water of 80 °C for 1000 hours.

The results of the testing done by Wavin showed that all the pipes passed all the tests. Which means that all the pipes met the requirements according to standard DS/EN 1555 and standard DS 2131-2. The tests showed that the pipe pieces had not been damaged by aging and operation, and they were in line with new pipes. Meaning that, the oldest of which was 34 years at the time, could immediately be welded and used at full operating pressure for the next 50 years. However, it is recommended that in the next 10-15 years the state of the existing network is investigated again.

For the case of the Rårup project, a recommendation could be made that an unused section of the gas network to be dug up and similar tests performed as carried out by Wavin.

2.4 Distance between pipes

All new pipes and cables are established according to the Danish norm DS475. The figure 6 shows the minimum distance between pipes (Dansk Standard, 2015):

Tabel 4.6.1 – Frie lodrette (krydsning – øverste tal) og vandrette (parallel – nederste tal) minimumafstande ved knebne pladsforhold mellem forskellige ledningstyper, jf. 4.6.2-4.6.9

d: diameter K: krydsning/lodret L: ledningsspecifikt P: parallel/vandret S: særlig vurdering nødvendig U: spænding [a]: forudsætter tætte samlinger [b]: forøges, hvis vandledning er dybest		afløb: beton mv.	afløb: plast	Dræn d ≤ 160 mm	vand: plast	vand: støbejern og stål	gas: transmissionsledninger 5-8 MPa	gas: fordelingsledninger 1-4 MPa	gas: distributions- og stikledninger af PEM	gas: distributions- og stikledninger ikke af PEM	olieprodukter	fjernvarme: d > 400 mm	fjernvarme: d ≤ 400 mm	el: U > 100 kV	el: 30 kV ≤ U ≤ 100 kV	el: 1 kV < U < 30 kV	el: U ≤ 1 kV	Kommunikation
afløb: beton mv.	K	L	L	L	0,1[a]	0,2[a]	0,3	0,3	0,3	0,3	S	0,2	0,2	S	0,1	0,1	0,1	0,1
	P				0,5[b]	0,5[b]	5,0	1,0	1,0	1,0		0,3	0,3		0,3	0,3	0,3	0,3
afløb: plast		K	L	L	0,1[a]	0,1[a]	0,3	0,3	0,3	0,3	S	0,1	0,1	S	0,1	0,1	0,1	0,1
		P			0,5[b]	0,5[b]	5,0	1,0	1,0	1,0		0,3	0,3		0,3	0,3	0,3	0,3
afløb: markdræn d ≤ 160 mm			K	L	0,1[a]	0,1[a]	0,15	0,15	0,15	0,15	S	0,1	0,1	S	0,1	0,1	0,1	0,1
			P		0,5[b]	0,5[b]	5,0	1,0	1,0	1,0		0,3	0,3		0,3	0,3	0,3	0,3
vand: plast				K	L	L	0,3	0,3	0,3	0,3[a]	S	0,1	0,1	S	0,1	0,1	0,1	0,1
				P			5,0	0,5	0,5	0,5		1,0	1,0		0,5	0,5	0,3	0,3
vand: støbejern og stål					K	L	0,3	0,3	0,3	0,3	S	0,2	0,2	S	0,1	0,1	0,1	0,1
					P		5,0	0,5	0,5	0,5		1,0	0,7		0,5	0,5	0,3	0,3
gas: transmissionsledninger 5-8 Mpa						K	L	L	L	L	S	0,5	0,5	S	S	S	0,3	0,3
						P						5,0	5,0				5,0	5,0
gas: fordelingsledninger 1-4 Mpa							K	L	L	L	S	0,5	0,5	S	0,3	0,3	0,3	0,3
							P					1,0	1,0		1,0	0,3	0,3	0,3
gas: distributions- og stikledninger af PEM								K	L	L	S	1,0	1,0	S	0,75	0,75	0,3	0,3
								P				2,0	2,0		0,75	0,75	0,3	0,3
gas: distributions- og stikledninger ikke af PEM									K	L	S	0,1	0,1	S	0,3	0,3	0,1	0,1
									P			0,3	0,3		0,5	0,3	0,3	0,3
Olieprodukter											L	S	S	S	S	S	S	S
fjernvarme: d > 400 mm											K	L	L	S	S	0,3	0,2	0,1
											P					1,0	1,0	0,3
fjernvarme: d ≤ 400 mm												K	L	S	S	0,2	0,1	0,1
												P				1,0	0,5	0,3

Figure 6: Overview of the safety distance between pipes. (Dansk Standard, 2015)

District heating pipes must be placed with a distance of at least 1 meter to drinking water pipes if they are placed parallel to each other. The distance between two water pipes in parallel must be determined individually for each case. Other distances are required if pipes are crossing each other (the upper part of the cells in the matrix).
The owner of the latest placed pipe or cable has the responsibility to ensure that the safety distances are adhered to.
Another document which covers ground source heating systems is the Danish "Bekendtgørelse om jordvarmeanlæg" (Retsinformation, 2017). Pipes that are used with the ground as heat source, must be insulated against condensation if they are closer than 1.5 meters to buildings and less than 1 meter away from drinking water or wastewater pipes, according to paragraph 10. If the pipes are closer than 0.6 meters to a private area, the owner needs to approve the placement.

2.5 Geology

The analysis of the geology in the project area was done by investigating the database of GEUS and drillings from Jupiter database. Since the project regards a horizontal heat exchanger, the relevant depth is around 1.5 m. The depth between 0 - 4.1 m was investigated.
In the case of heat exchange, the geology in the area plays a vital role. Based on the geology, the heat conductivity can be determined. Moreover, saturated ground conditions, which are experienced in shallow depths play a vital role in changes of the ground's properties. Sand and other similar soil types can accumulate water, which increases the saturation probability. That results in higher variations of the heat conductivity.

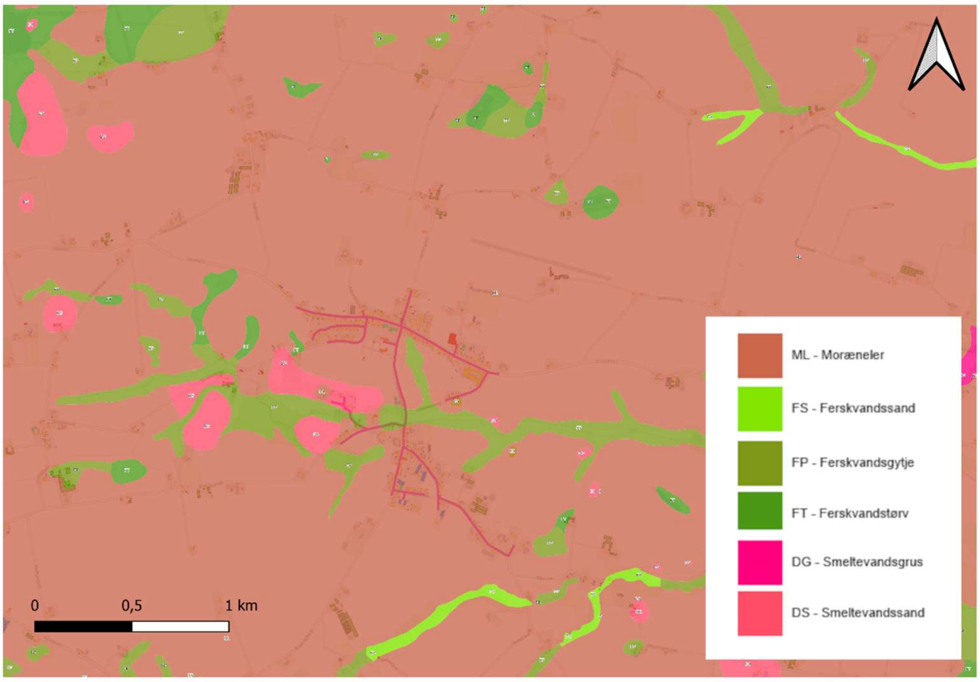

Figure 7: Geology in Rårup (GEUS, 2023)

2.6 Thermal properties of the soil

2.6.1 Heat conductivity and heat capacity

For calculations on heat conductivity and capacity, the GEUS drilling **117. 846** in 2008 made by NIRAS was investigated. Figure 8 below shows the location of the drilling:

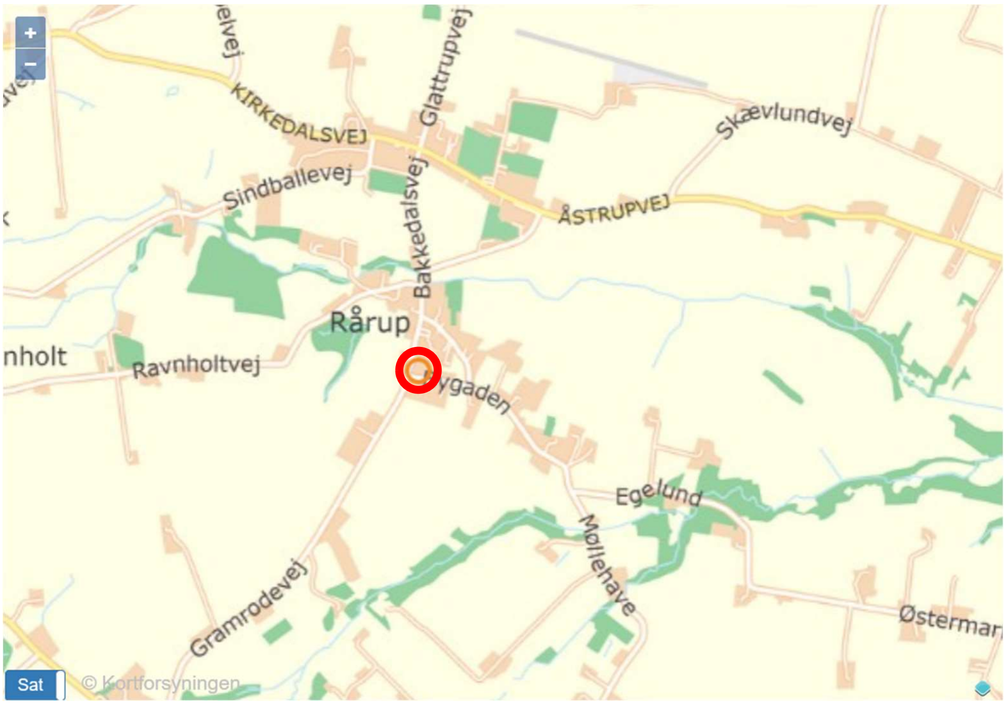

Figure 8: Location of the drilling. (GEUS, 2023)

Since the project regards only the depth of the pipe placement and the placement of the heat exchanger, the depth up to 4.1 m was examined.

Top*	Bund*	Top**	Bund**	DGU-symbol	Beskrivelse
0	0,25	-	-	fyld - o	(fyld). Prøve udtaget ved ,2 m. Anden Beskrivelse: FYLD: SAND, misfarvet.
0,25	0,75	-	-	fyld - o	(fyld). Prøve udtaget ved ,5 m. Anden Beskrivelse: FYLD: LER, st. sandet, misfarvet.
0,75	1,25	-	-	fyld - o	(fyld). Prøve udtaget ved 1 m. Anden Beskrivelse: FYLD: LER, st. sandet, brun.
1,25	1,7	-	-	fyld - o	(fyld). Prøve udtaget ved 1,5 m. Anden Beskrivelse: FYLD: LER, st. sandet, brun.
1,7	2,1	-	-	sand - s	(sand). Prøve udtaget ved 2 m. Anden Beskrivelse: SAND, fin - ml., lys brun.
2,1	2,75	-	-	ler - l	(ler). Prøve udtaget ved 2,5 m. Anden Beskrivelse: LER, st. sandet, misfarvet.
2,75	3,1	-	-	ler - l	(ler). Prøve udtaget ved 3 m. Anden Beskrivelse: LER, st. sandet, misfarvet.
3,1	3,9	-	-	sand - s	(sand). Prøve udtaget ved 3,5 m. Anden Beskrivelse: SAND, fin - ml., lerslirer, fugtig, misfarvet.
3,9	4,1	-	-	ler - l	(ler). Prøve udtaget ved 4 m. Anden Beskrivelse: LER, sandet, tør.
4,1	4,75	-	-	ler - l	(ler). Prøve udtaget ved 4,5 m. Anden Beskrivelse: LER, sandet, stenet, kalkholdig, tør, gråbrun.
4,75	5	-	-	ler - l	(ler). Prøve udtaget ved 5 m. Anden Beskrivelse: LER, sandet, stenet, kalkholdig, tør, gråbrun.

Figure 9: Borehole contents from the GEUS database (GEUS, 2023)

On a Figure 10 below, a graphic visualisation of the borehole can be seen:

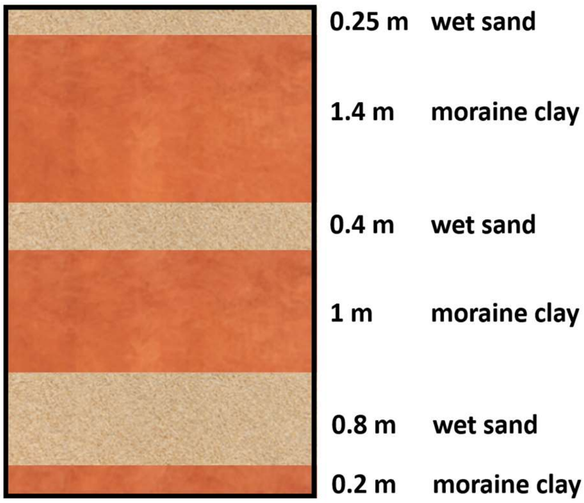

Figure 10: Visualisation of the borehole.

Values for thermal conductivity and volumetric capacity were taken from the software EED (Earth Energy Designer), that is used to design borehole heat exchangers. Clay was estimated as moist, sand was estimated saturated.

- Volumetric heat capacity of sand: $2.2\ \frac{\mathrm{MJ}}{\mathrm{m}^3 * \mathrm{K}}$
- Thermal conductivity of sand: $1.73\ \frac{\mathrm{W}}{\mathrm{m} * \mathrm{K}}$
- Volumetric heat capacity of clay: $2.4\ \frac{\mathrm{MJ}}{\mathrm{m}^3 * \mathrm{K}}$
- Thermal conductivity of clay: $1.6\ \frac{\mathrm{W}}{\mathrm{m} * \mathrm{K}}$

The ratio of sand in the forementioned borehole was calculated to be 35,8% filled with sand and 64,2% filled with clay. Using these ratios, the average volumetric heat capacity and thermal conductivity were calculated.

- Volumetric heat capacity: $2.328\ \frac{\mathrm{MJ}}{\mathrm{m}^3 * \mathrm{K}}$
- Thermal conductivity: $1.647\ \frac{\mathrm{W}}{\mathrm{m} * \mathrm{K}}$

2.7 Reynolds number

Reynolds number (Re) is a dimensionless value. It is often described as the ratio between the inertial forces to viscous forces. Reynolds number categorizes fluid flow into 3 regimes (Menon, 2015):

Laminar flow: Re < 2000
Transition flow: 4000 > Re > 2000
Turbulent flow Re > 4000

Based on research it has been observed that there is a correlation between the increase of Reynolds number and the increase of heat transfer. Therefore, it can be stated that for heating, turbulent flow must be targeted to achieve (F. VAHİDİNİA, 2015).

3 Methods

The approach to investigate whether the existing gas pipes can be reused for termonet was to find out if the gas pipe dimensions suit the pipe dimensions needed for termonet. Therefore, a termonet with same pipe placement as the gas network was designed to compare the calculated termonet pipe diameters with the existing gas pipe diameters. For dimensioning the termonet, SCATER software was used.

3.1 Introduction of SCATER software

SCATER (SCreening Aid for Termonet Energy Renewable) is a software to dimension termonet systems. The software is still under development and only available in python code. It was the first time that SCATER was used by someone other than the developers.

The software calculates suggested distribution pipes diameters choosing from a pipe catalogue attached. Also, Reynolds numbers of the different pipe sections are being calculated. Moreover, SCATER calculates the required lengths needed for supplemental horizontal heat exchanger/ borehole heat exchanger including pressure gradient and Reynolds number. The input needed to feed the termonet design software (SCATER) can be grouped into three parts:

- **Consumer data input:**
  The consumer input is described in the so-called HP.dat file (Heat pump file). The HP.dat file lists all consumers and describes the characteristics of each, most importantly the heat loads for each consumer (see chapter 3.3).
- **Pipe network data input:**
  The pipe network input is described in the so-called TOPO.dat file (Topology file). The TOPO.dat file describes the layout of the network and the location of the consumers in the network (see chapter 3.4).
- **User specified input:**
  The user specified input is being applied in the python script itself, where general values for e.g., brine properties, design temperature or maximum pressure gradient for the systems can be set (see chapter 3.5).

3.2 Limitations of SCATER software

SCATER software does not calculate pressure properties of distribution net. Hence, no statements about operation pressure or needed pumping power can be made without additional hydraulic calculations. Also, no ring connections can be simulated and only one supplementary heat exchanger at one location can be designed by the software. This means that the software approaches a tree structure for the termonet.
Furthermore, the software assumes same soil types for the whole network for both the termonet distribution pipes and the horizontal heat exchanger meaning that no distinction between soil properties of already sand embedded gas pipes and newly laid termonet/ heat exchanger pipes can be made.

3.3 Consumer data input

Chapter 3.3.1 describes the processing of the raw data to the needed input data the termonet was designed with.
The consumer data input for SCATER software (HP.dat file) needs to contain following information to simulate a termonet for heating purposes:

- Heat pump ID (representing every consumer with an ID)
- Yearly heating load in W
- Winter heating load in W
- Daily heating load in W
- Year COP
- Winter COP
- Hour COP
- Temperature difference Δt at the heat pump

The heat pump file also contains properties for cooling. As cooling is not included in this termonet project, cooling related input values can be disregarded. Moreover, it must be noted that specific consumption data is subject to GDPR and therefore no consumption data for single houses can be shown in the report.

3.3.1 Consumers and consumption raw data

The termonet for Rårup was designed assuming that all consumers currently using gas or oil as heat source are part of the system, although not all these consumers will be connected to the termonet in first place.
The expected heat demands were calculated based on EVIDA and Bygnings- og Boligregistret (BBR) data from where annual heat consumptions for each building were obtained.

Gas consumption

Gas consumption data was provided by EVIDA. The dataset contained the expected gas consumption in kWh per year for every gas consumer in Rårup based on their gas consumption between summer 2021 and summer 2022 and assuming normal climate conditions (Schmidt, 2023). The expected annual consumption was multiplied by 95 % considering the efficiency of the now installed gas boilers and therefore higher gas consumption than actual heat consumption. Consumers with 0 kWh gas consumption were neglected.

Oil consumption

Oil consumption data was provided by NIRAS. The data is based on Bygnings- og Boligregistret (BBR) data as no historical heat consumption figures were available. From the BBR, buildings were categorized after usage type and age. For each of these categories experience values for specific heat consumption in kWh per m^2 from Statens Byggeforsknings Institut were assigned (Statens Byggeforsknings Instituts , 2021). Multiplying the specific heat consumption for the usage/age categories with the size of the buildings, an estimate for yearly heat consumption per building was made.

In total the case includes 124 termonet consumers where 101 consumers currently are heated by natural gas and 23 by oil (see table 2 below).

Supply	Count of Supply	Sum of MWh/year
Natural gas	101	1621.20
Oil	23	618.78
Grand Total	**124**	**2239.98**

Table 2: Division of the consumers by heat source

Figure 11 below shows the distribution of the current gas and oil consumers.

Figure 11: Location of the consumers in Rårup

3.3.2 Consumption data processing (yearly, winter, daily heat loads)

From the annual heat consumptions of the consumers the specific inputs for the heat pump input file can be generated. The yearly heating load describes the load at which the heat pump runs on average over the whole year. The winter heating load describes the load the heat pump averagely runs during the 4 winter months where around 40 % of the annual heating consumption is consumed. The daily heating load equals the peak load but rounded up in 2 kW steps for simplicity's sake for the setup of the topology input file (see chapter 3.4). The peak load was determined by assuming 1800 full load equivalent running hours (FLEQ) for all heat pumps (GEOTRAINET, 2011). Figure 12 below shows the process of calculating the heat load input data from the annual heat consumption.

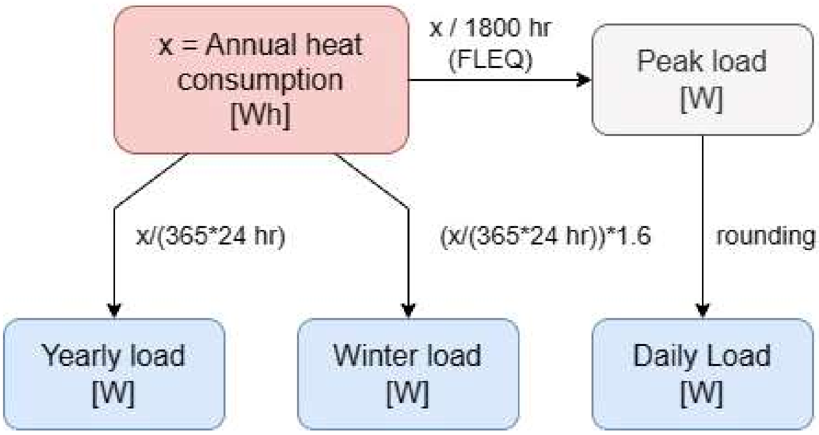

Figure 12: Derivation of heat load input data

In the construction of the input data, it was noticed that there are two consumers with exceptionally high heat demands (>180 MWh/year, >100 kW daily load). It was assumed that these consumers will highly affect the sizing of the termonet and might harm the common benefit. Therefore, these two consumers were neglected in the first place resulting in 122 consumers.

3.3.3 COP factors

To each of the three loads, COP factors for the heat pump must be assigned. The yearly COP factor is the average COP factor of the heat pump during the whole year. The winter COP factor is the seasonal average COP factor for the four winter months. Both COP factors were set to 3.6. The daily COP factor is the COP factor during peak load and was set to 3. (Spitler & Gehlin, 2019)

3.3.4 Temperature difference

The temperature difference Δt describes the heat extraction from the brine between supply and return at the heat pump. Typical value for termonet systems is 3 °C, which was also chosen for this case (Poulsen, 2023).

3.3.5 Uncertainties in data and design parameters

It must be noted that the actual heat consumption might be different from the design heat consumption as heat demand patterns might change. Moreover, gas consumption data is not only specified for heating purposes. Consumed gas can also be used for e.g., gas stoves or other purposes while gas is not necessarily the only heating source.

Oil consumption data are experience values of comparable buildings and are therefore not based on the actual historical data. Furthermore, BBR data is primarily updated by the owners of the buildings, and recent events regarding the estimation of the "Varmecheck" to houseowners during the energy crisis showed that these datasets are not updated properly (Ritzau, 2023). This could mean that some of the consumers which are listed as oil-consumers already have switched to a different heat source without updating their status in the BBR database. Therefore, all annual consumption data must be used with caution.

Also, the value of FLEQ has significant impact to the termonet design as less full load hours would increase the peak load and vice versa. However, comparing to different experience values and sources, 1800 FLEQ were assumed to be suitable for all consumers, both domestic and industrial/public (GEOTRAINET, 2011).

Same applies to the COP factors. Higher COP factors mean that a higher share of the heat consumption needs to be provided from the termonet and vice versa. As COP factors are highly dependent on operation and often vary from manufacturers data, it was challenging to make a qualified estimation. For designing the termonet with reasonable COP factors, average values from different sources and experience values were used (Kun Zhou, 2020) (Mohammad Habibi, 2018).

3.3.6 Consumption data input overview

Below two rows of the heat pump file data can be seen. The complete heat pump data input file can be found in appendix A.

Heat pump ID	Yearly heating load (W)	Winter heating load (W)	Daily heating load (W)	Year COP	Winter COP	Hour COP	dT HP heating
?	705	1129	4000	3.6	3.6	3	3
?	958	1534	6000	3.6	3.6	3	3

Table 3: Example of the heat pump file data

3.4 Topology data input

The topology data input for SCATER software (TOPO.dat file) needs to contain following information:

- Section name
- SDR value of the section
- Trace length in m
- Number of traces
- HP ID vector (accessing the specific consumer data from the HP.dat file)

Chapter 3.5 describes how the layout of the termonet was designed and how the topology input for SCATER was set up.

3.4.1 Existing gas network

To compare existing gas pipe diameters with needed termonet pipe diameters, the topology of the termonet was based on the placement of the existing gas pipes. Figure 13 below shows the layout of the initial gas network of Rårup and its dimensions in mm outer diameter.

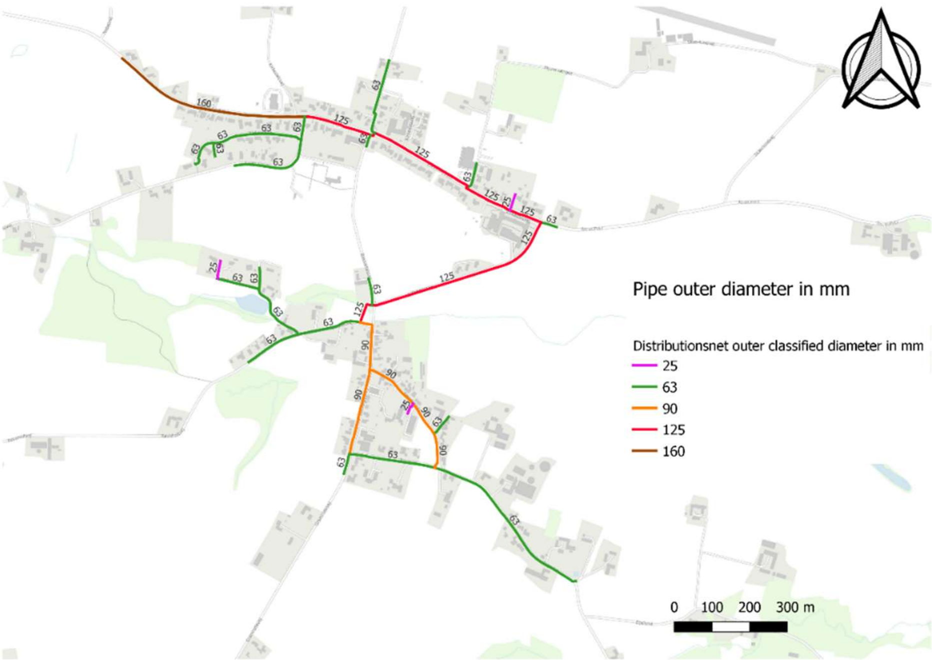

Figure 13: The existing gas network classified by pipe diameter

In total the gas network is 5.25 km long. Table 4 below shows the sum of lengths per pipe diameter.

Pipe outer diameter [mm]	Sum of Length [m]
25	123.41
63	2574.59
90	728.49
125	1288.02
160	536.55
Grand Total	**5251.06**

Table 4: Lengths per pipe diameter

Service pipes are between 25 mm and 63 mm in size, but they also change diameter between distribution network and house connections. In total 3.09 km service pipes in the network resulting in an average of 19.5 m per consumer.

3.4.2 Termonet layout

Knowing the placement of the pipes, the topography of longest pipe path through Rårup was examined by SCALGO elevation tool (see figure 14).

Figure 14: Elevation profile through the networks location in Rårup

As seen on figure 14 above, the elevation ranges between 27 m to 50 m above sea level. The termonet was split into two single systems, a northern and a southern part. This was done to keep pressures low, to save pumping power, and mitigate pressure limit issues by reusing the gas pipes. Moreover, the division of the network into two leads to less concentrated mass flows and therefore lower pipe diameter requirements as two supplementary heat exchangers distribute the heat more locally than one heat exchanger for all consumers (heat exchanger placement see section 3.4.3.)

Since no ring connections can be simulated the existing ring connection in the southern part was cut between Smedegade and Bygaden. To compare whether gas pipe diameters match with needed termonet pipe diameters, same pipe sections must be simulated. Therefore, termonet pipe sections were designed after gas pipe diameter sections.

The final overall topology layout of the termonet can be seen in figure 15 and 16 below. Every color represents one pipe section. Also, all consumers are shown with their heat pump IDs.

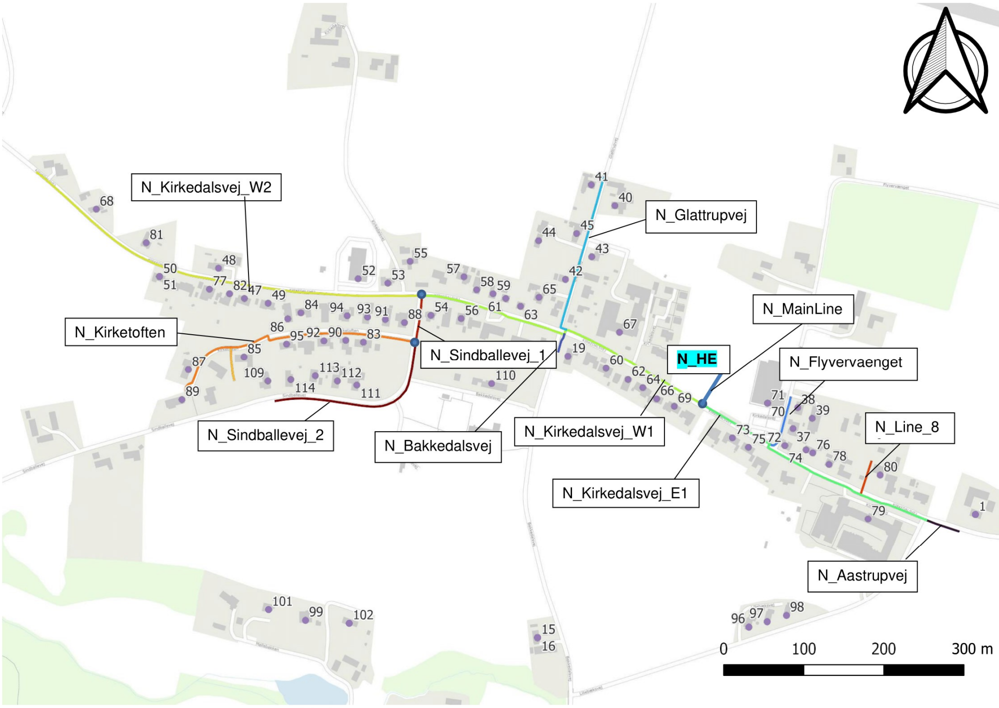

Figure 15: Northern termonet part with the planned location for the HHE (turquoise)

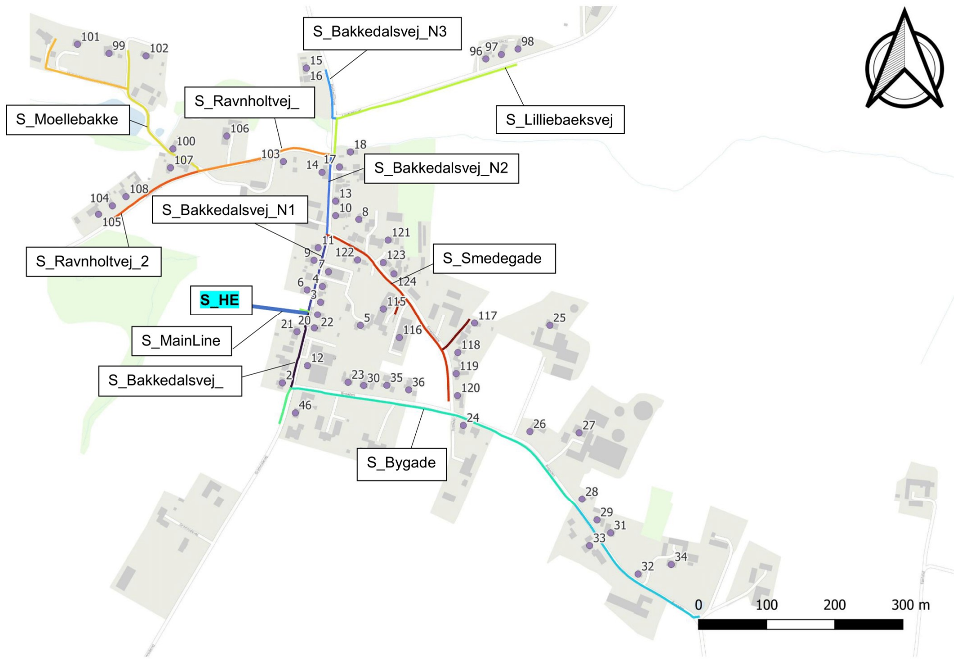

Figure 16: Southern termonet part with the planned location for the HHE (turquoise)

3.4.3 Heat exchanger placement

Heat exchangers were placed in a way that they are central and can be connected to the biggest available pipe as highest mass flow occurs near the heat exchangers. The second condition was available space to place the heat exchanger itself, preferably public areas. In the northern part the heat exchanger was placed at Kirkedalsvej near Rårup-hallen as a 125 mm gas pipe is laid and public football fields could be considered for the heat exchanger placement. In the southern part, the heat exchanger was placed at Bakkedalsvej where the heat exchanger was assumed to be on the field with a connection through an empty property to the 90 mm pipe.

3.4.4 TOPO file setup

The defining parameter from the heat pump file for the pipe diameters is the daily load. As the network was divided into two systems, two topology files must be created. Pipe sections are named after street names as in figure 15 and 16. The SDR value for all pipes was set to 17 as the standard value.

For each pipe section the consumers that need to be supplied through this specific pipe section were assigned by the heat pump ID. The main pipe section to the heat exchanger contains all heat pump IDs. The next section contains all the heat pump IDs it needs to supply itself and its branches afterwards. This principle continues until the last branch of the network's tree structure is reached.

The daily heating loads of all consumers assigned to the specific sections were used to calculate pipe diameters. Decreasing heat loads by outbranching service pipes to consumers during a section were not considered.

Service pipes were calculated in the same way. For simplicity's sake, consumer peak loads were grouped in 2 kW steps, so service pipes for alike consumers can be calculated by just one input row and adjusting the number of traces. The trace length of the service pipes was estimated to be 20 m per consumer.

3.4.5 Topology data input overview

Below two rows of the topology file data can be seen. Both complete topology data input files can be found as appendix B.

Section	SDR	Trace_(m)	Number_of_traces	HP_ID_vector
N_Flyvervaenget	17	71	1	37,38,39
N_Kirkedalsvej_W2	17	528	1	68,81,51,50,48,77,82,47,49,93,94,52,53,55

Table 5: Example of the topology input

3.5 User specified input

In the user specific input values for other properties in the termonet are defined. Below, all relevant variables are described and chosen values explained.

3.5.1 Parameters for the brine

The brine chosen was 30 %-IPA and 70 % water, as well as in previous termonet projects (Termonet, 2022). IPA-sprit consists of 90 % ethanol and 10 % isopropyl alcohol. Therefore, in total, the brine consists of 27 % ethanol, 3 % isopropyl alcohol and 70 % water. The values for 28 % ethanol brine at 10 °C were taken from the software Earth Energy Designer (EED):

- Density (rho): **0.963** $\frac{\boldsymbol{kg}}{\boldsymbol{m^3}}$
- Specific heat capacity (c): **4232** $\frac{\boldsymbol{J}}{\boldsymbol{kg*K}}$
- Kinematic viscosity (mu): **0.0039** $\frac{\boldsymbol{kg}}{\boldsymbol{m*s}}$
- Thermal conductivity (l): **0.415** $\frac{\boldsymbol{W}}{\boldsymbol{m*K}}$

3.5.2 Parameters for the network

D_gridpipes $[\boldsymbol{m}]$

Distance between the supply and return pipe. After creating the detailed drawing of the network including the LER-data (existing pipe and cable data), it was clear that in practice it is not possible to keep the ideal 1 meter spacing between the existing gas network and the newly laid pipe in all sections. This is due to the number of existing pipes and cables in the ground and due to the proximity to the private properties. It was assumed that an average spacing of **0.8 meters** can be achieved in the entire network. The spacing between service pipes is going to be smaller, but as the overall length of the service pipes is short, this is neglected.

dpdL_t $\left[\frac{Pa}{m}\right]$

Pressure loss per meter of pipe. For ground source heating it is usually between 100 and 300 Pa/m (Poulsen, 2023). The value chosen was **200** $\frac{Pa}{m}$**.**

l_p $\left[\frac{W}{m*K}\right]$

Heat conductivity of the pipes. A standard value of **0.4** $\frac{W}{m*K}$ was chosen based on manufacturers' data (Wavin, 2023).

l_s_H $\left[\frac{W}{m*K}\right]$

Soil heat conductivity when the termonet is in heating mode. Value of **1.647** $\frac{\mathrm{W}}{\mathrm{m*K}}$ was chosen (see the geology section).

rhoc_S $\left[\frac{J}{m^3*K}\right]$

Volumetric heat capacity of the soil. Value of **2.328** $\frac{\mathrm{MJ}}{\mathrm{m^3*K}}$ was chosen, which corresponds to 2.328e6 $\frac{J}{m^3*K}$ in the software (see the geology section).

z_grid $[m]$

Depth in which the pipe is placed. **1.2 m** was used as a standard value.

3.5.3 Parameters for the consumers/ heat pump

Ti_H $[°C]$

Design temperature of the system in heating mode. **-3 °C** was chosen as the minimum inlet temperature to the heat pumps. Legally the lowest temperature allowed is -4 °C for a short period, according to the "Bekendgørelse om jordvarmeanlæg" §14 stk 4. (Retsinformation, 2017).

SF

Ratio of peak heating demand to be covered by the heat pump [0-1]. If SF is equal to 0.8 then the heat pump delivers 80 % of the peak heating load. The deficit is then supplied by an auxiliary heating device. The chosen value was **1**.

3.5.4 Parameters for the Horizontal heat exchanger

N_HHE

Number of loops. This value was used as a parameter. It was set to **70** to keep the length of the loops below 500 m.

d $[\boldsymbol{m}]$

Outer diameter of the heat exchanger pipe. The value chosen was **0.04 m** as it is standard for horizontal heat exchanger pipes (Jensen, Hvenegaard, & Pedersen, 2011).

SDR

Ratio of diameter to the wall thickness of the pipe. The value of **17** was used for designing a new network. However, existing pipes already have SDR ratio assigned. For those pipes the SDR value was assigned accordingly.

D $[\boldsymbol{m}]$

Pipe segment spacing. The distance between the pipes in the HHE is set to **1** meter to optimize the area required for the heat exchanger without having thermal short circuiting.

3.5.5 Parameters for the borehole heat exchanger

Borehole heat exchanger simulation was used only to compare and does not affect the result of the project. Hence, values were not changed from default values in SCATER.

r_b $[\boldsymbol{m}]$

Borehole radius. Default value of **0.152/2 m** was chosen.

r_p $[\boldsymbol{m}]$

Outer radius of U pipe. Default value of **0.02** was chosen.

SDR

Ratio of diameter to the wall thickness of the pipe. Default value of **11** was used.

l_ss $\left[\frac{\boldsymbol{W}}{\boldsymbol{m*K}}\right]$

Soil thermal conductivity along BHEs. Default value of **1.66** $\left[\frac{\boldsymbol{W}}{\boldsymbol{m*K}}\right]$ was chosen.

rhoc_ss $\left[\frac{\boldsymbol{J}}{\boldsymbol{m^3*K}}\right]$

Volumetric heat capacity of soil along the BHE. Default value of **2.65** $\frac{\boldsymbol{MJ}}{\boldsymbol{m^3*K}}$ was chosen, which corresponds to 2.65e6 $\frac{J}{m^3*K}$ in the software.

l_g $\left[\frac{\boldsymbol{W}}{\boldsymbol{m*K}}\right]$

Grout thermal conductivity. Default value of **1.75** $\left[\frac{\boldsymbol{W}}{\boldsymbol{m*K}}\right]$ was chosen.

rhoc_g $\left[\frac{\boldsymbol{J}}{\boldsymbol{m^3*K}}\right]$

Grout volumetric heat capacity

Value of **3** $\frac{\boldsymbol{MJ}}{\boldsymbol{m^3*K}}$ was chosen, which corresponds to 3e6 in the software.

D_pipes $[m]$

Wall to wall distance (U-pipe legs). Default value of **0.015 m** was chosen.

NX/NY

Description of the number of boreholes and the layout in x and y axis. This value was used as a parameter. Final setup was: **NX = 10, NY = 10**, to keep the boreholes shorter than 130 m.

Dx/Dy $[m]$

Distances between the boreholes in the x and y direction in meters. Default value of **15** m was used both for Dx and Dy.

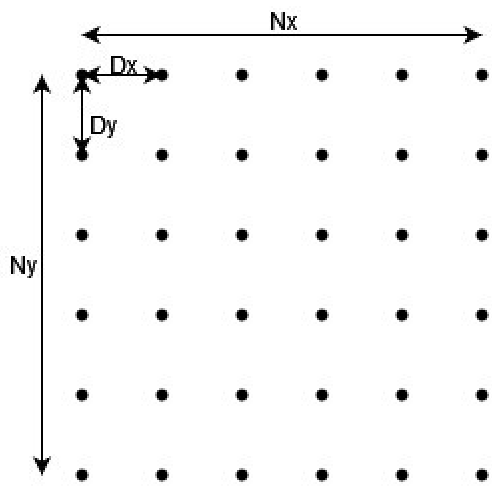

Figure 17: Explanation of variables used for the spacing of boreholes.

4 Results and findings

4.1 Placement of the termonet pipes

An AutoCad drawing was created to create an estimation of a realistic placement of the new termonet pipes. For this LER data (existing pipe and cables in the area) provided by NIRAS was combined with publicly available data for road layout and the cadaster registration (matrikelkort).

The new termonet pipe was placed parallel to the existing gas pipes in the layout that is described in paragraph 3.4. If possible, the new termonet pipe was placed with 1 m distance to gas pipes. Furthermore, the pipe was placed in public areas, outside of private properties and if possible, in unpaved areas. The full resolution of the map can be found in Appendix C.

4.1.1 Distance to drinking water pipes

Rårup waterworks was contacted to determine the safety distance between the termonet pipes and the existing drinking water network. The contact person referred to termonet as cold district heating and hence the pipes needed to be placed according to the district heating pipe distance in accordance with DS 475.

This results in six stretches of the existing gas network, where the minimum distance of at least 1 m (parallel) cannot be satisfied. The stretches are illustrated in figure 18 below.

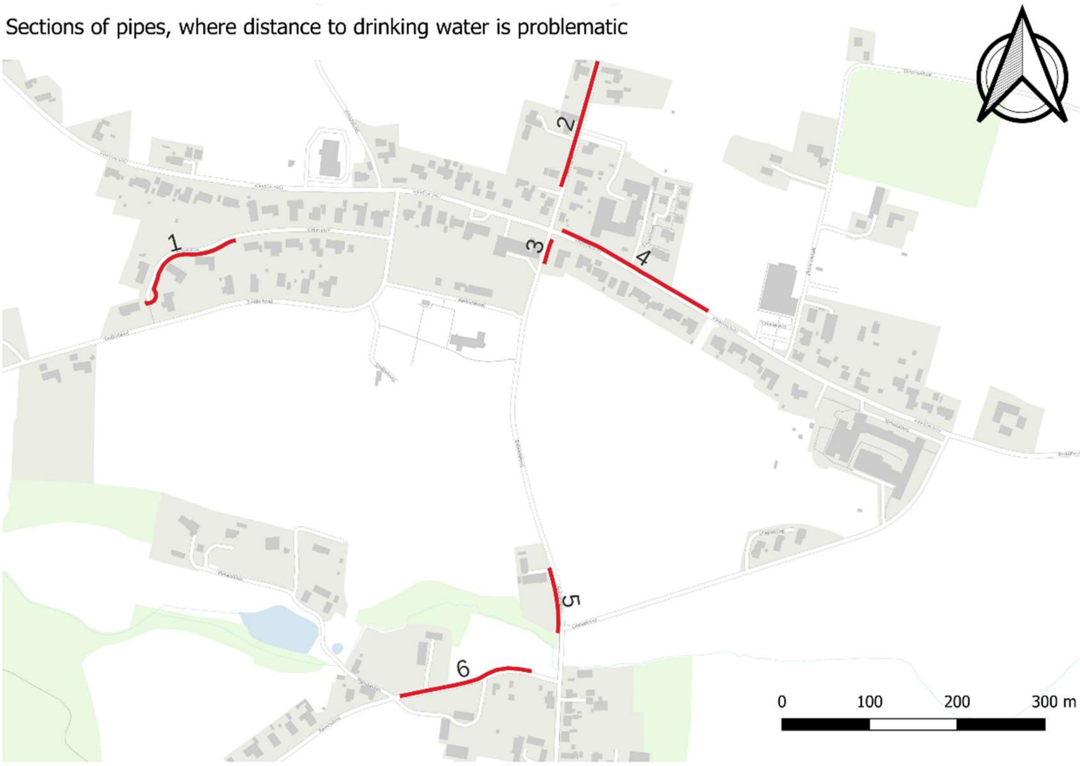

Figure 18: Overview of the stetches where the existing gas pipes are closer than 1 meter to the drinking water pipes

Table 6 below lists the stretches length and the distance to the drinking water pipes:

ID	Road name	Length of section [m]	Distance between pipes [m]
1	Kirketoften	142	0.5
2	Glattrupvej	145	0.2-0.3
3	Bakkedalsvej N	42	0.3
4	Kirkedalsvej	186	0.2-0.6
5	Bakkedalsvej S	29	0.1-0.3
6	Ravnholtvej	151	0.2-0.8
	Total	695	

Table 6: Overview of the distances where the distance to drinking water pipes is less than 1 meter

As seen in table above, approx. 695 meters of gas pipes would be too close to the drinking water pipe when categorized as district heating. The distances are measured from the received LER-data and hence limited by the accuracy of the received data. Furthermore, the distances between pipes were only measured in the x and y plane and does not include the additional distance from the z-axis (depth of the pipes).

4.2 SCATER termonet simulation

In chapter 3 the setup of the SCATER software was explained. In this chapter the results for the termonet simulation are presented.

4.2.1 Distribution network in the northern termonet

Results for calculated pipe diameters of the northern termonet can be seen on table 7 and figure 19 below. Results can be seen on Table 7 and Figure 19.

Section name:	Termonet diameter [mm]	Reynolds nr.
N_Main_Line	160	42856
N_Kirkedalsvej_E1	90	18161
N_Kirkedalsvej_W1	160	33060
N_Line_80	32	3643
N_Aastrupvej	32	2429
N_Flyvervaenget	63	10132
N_Kirkedalsvej_W2	90	15926
N_Glattrupvej	75	10621
N_Bakkedalsvej	32	2429
N_Sindballevej_1	90	18859
N_Kirketoften	75	11932
N_Sindballevej_2	75	10621

Table 7: Pipe diameters and Reynolds numbers in the northern part

4.2.2 Distribution network in the southern termonet

Results for calculated pipe diameters of the southern termonet can be seen on table 8 and figure 19 below.

Section name:	Termonet diameter [mm]	Reynolds nr.
S_Main_Line	160	47019
S_Bakkedalsvej_N1	160	35176
S_Bakkedalsvej_S1	110	20090
S_Ravnholtvej_1	90	15341
S_Moellebakken	63	9015
S_Ravnholtvej_2	50	8124
S_Bakkedalsvej_N2	110	24795
S_Lillebaeksvej	63	12020
S_Bakkedalsvej_N3	63	9492
S_Smedegade	90	19886
S_Bygaden	90	19504

Table 8: Pipe diameters and Reynolds numbers in the southern part

Simulated pipe diameter results for both the northern and the southern part are visualized on a figure 19 below:

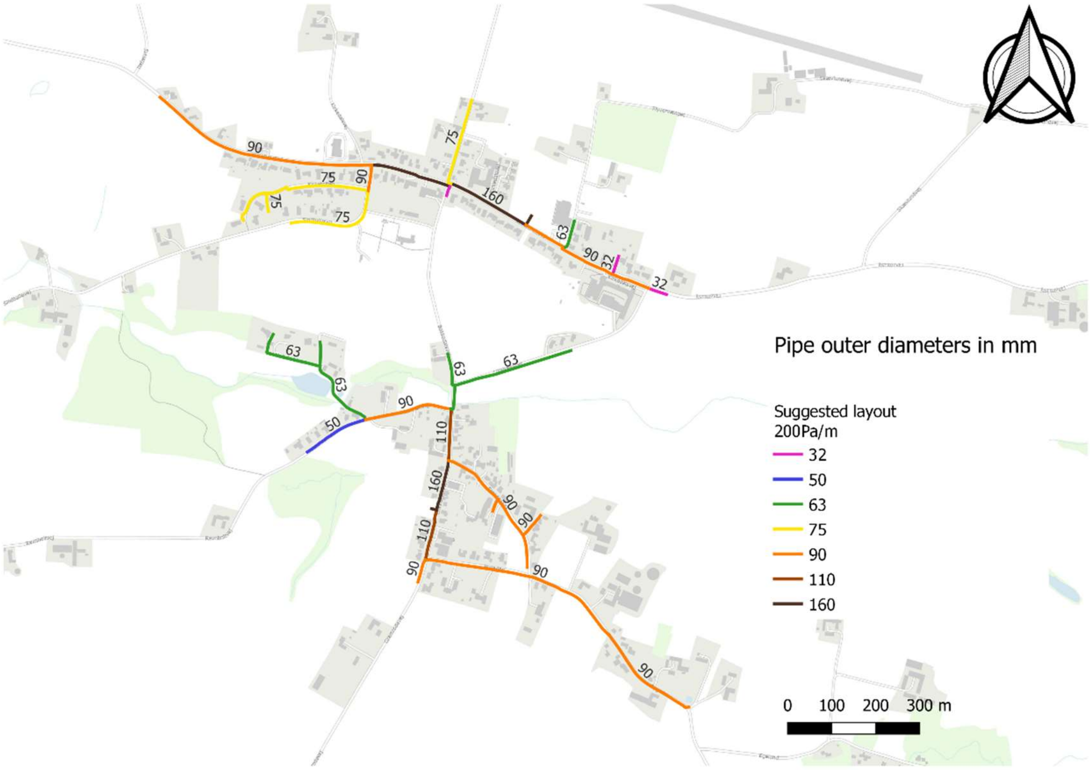

Figure 19: Suggested termonet dimensions for both the northern and southern part

4.2.3 Distribution network comparison: gas - termonet

Table 9 below compares the existing gas pipe diameter with the simulated termonet pipe diameters. If needed termonet diameters are equal or smaller than the gas pipes, it was considered that they are compatible.

Section name	Current Gas Diameter [mm]	Termonet dimater [mm]	Is it compatible?
N_Åstrupvej	63	32	YES
N_Bakkedalsvej	63	32	YES
N_Flyvervaenget	63	63	YES
N_Glattrupvej	63	75	NO
N_Kirkedalsvej_E1	125	90	YES
N_Kirkedalsvej_W1	125	160	NO
N_Kirkedalsvej_W2	160	90	YES
N_Kirketoften_2*	63	75	NO
N_Kirketoften	63	75	NO
N_Line_80	25	32	NO
N_Sindballevej_1	63	90	NO
N_Sindballevej_2	63	75	NO
S_Bakkedalsvej_S1	90	110	NO
S_Bakkedalsvej_N1	90	160	NO
S_Bakkedalsvej_N2	90	110	NO
S_Bakkedalsvej_N3	63	63	YES
S_Bygaden	63	90	NO
S_Bygaden_2*	63	90	NO
S_Bygaden_3*	90	90	YES
S_Lilliebaeksvej	125	63	YES
S_Moellebakken	63	63	YES
S_Møllebakken_2*	63	63	YES
S_Ravnholtvej_1	63	90	NO
S_Ravnholtvej_2	63	50	YES
S_Smedegade	90	90	YES
S_Smedegade_2*	25	90	NO
S_Smedegade_3*	63	90	NO

Table 9: Comparison of the pipe sizes between the existing network and simulation results

**These streets have separate sections in the existing gas network, but for the sake of simplicity, they were grouped into larger sections in the simulation*

Figure 20 below visualizes the results in a map:

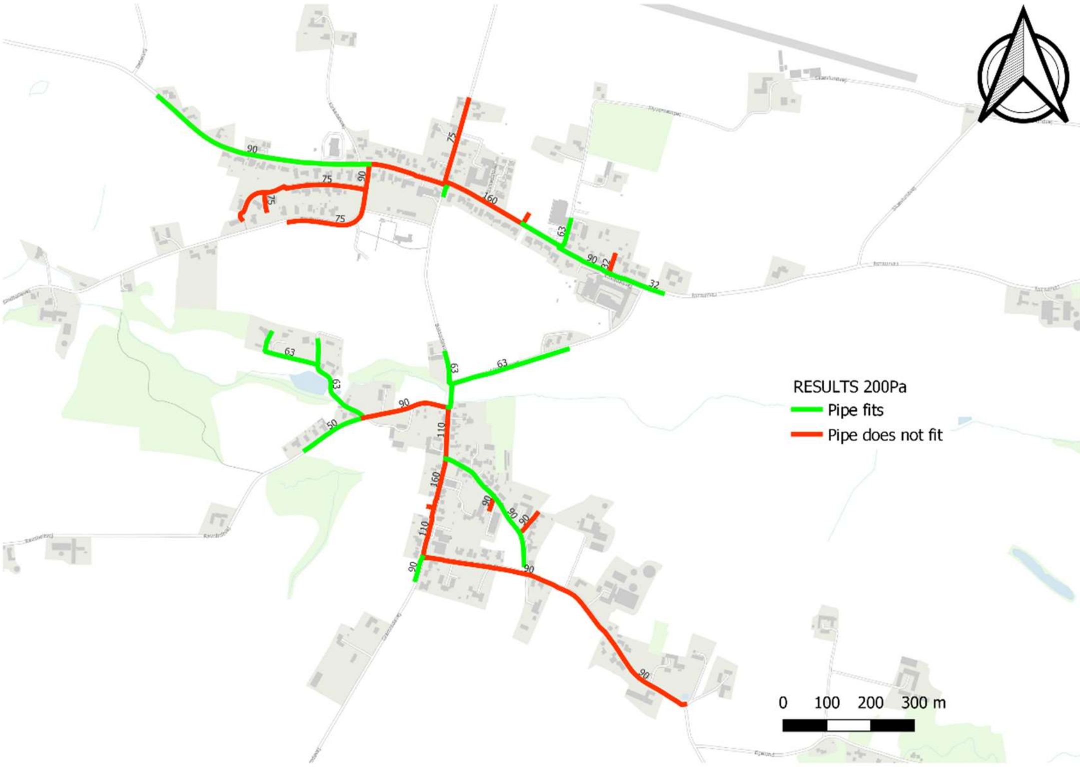

Figure 20: Comparison of the 200 Pa/m simulation to the existing gas network

In total, 2315 m of the gas network is compatible with the required termonet diameters (see table 10 below). The second column in table 10 compares the pipes identified in the first column up against the minimum distance required to the drinking water pipes, as earlier described in section 4.1.1. The difference in length is only minor because most of the pipes that are too close to the drinking water pipe also have too small diameters. As a result, 2215 m gas pipes can be reused.

Length of gas pipes that fits the diameter	**Length of gas pipes that fits the diameter and have at least 1 meter distance to DW pipes**
2315 m	2215 m

Table 10: Length of fitting pipes between the simulation and the existing simulation

4.2.4 Service pipes

The table below lists the simulated types of service pipes needed in both the northern and southern part, for certain consumer sizes.

Consumer size [kW]	Number of consumers	Size of service pipes [mm] (SDR 17)
4kW	17	32
6kW	26	32
8kW	23	40
10kW	26	40
12kW	12	50
14kW	4	50
16kW	3	50
18kW	2	50
20kW	3	50
26kW	1	63
28kW	3	63
30kW	2	63

Table 11: Required service pipe dimateters for both areas

In the existing gas network, a major part of the service pipe has an outer diameter of 25 mm. As the smallest required diameter was simulated to be 32 mm, all these cannot be utilized in the new termonet. A handful of the existing service pipes are 40 mm and 63 mm, but they either connect to the very biggest consumers or branch of into smaller diameters after a few meters. All service pipes were individually assessed, to check if the existing diameter fulfills the requirement of the simulation, but in no case with success. Hence, all service pipes must be replaced for the termonet.

4.2.5 Horizontal Heat Exchanger

The simulations in the SCATER software also return a value for the size of the HHE. The input values are described in section 3.5.4. Table 12 below illustrates the findings for the HHE and the overall energy distribution in the termonet:

Property	Northern Part	Southern part	Total
Peak load in area	564 kW	618 kW	1 182 kW
Length of distribution network (return and supply combined)	7284 m	7626 m	14 910 m
Percent of energy provided by distribution network	33 %	34 %	34 %
Number of loops in HHE	70	70	140
Length of each loop	320 m	313 m	
Total length of HHE	22 400 m	21 910 m	44 310 m
Area needed for HHE	2.24 ha	2.19 ha	4.43 ha
Max pressure loss in HHE	177 Pa/m	177 Pa/m	
Reynolds nr in HHE	5110	5110	
Total pipe length (Distribution net + HHE)	29 684 m	29 536 m	59 220 m
Energy provided by soil	19.000 W/m	20.923 W/m	19.959 W/m

Table 12: Overview of HHE results

The simulations show that the consumption is relatively evenly split between the northern and the southern termonet and the HHE lengths are almost identical, while the length and diameter of the distribution network varies in the areas.

Around 34% of the energy for the termonet is provided by the distribution network, which shows the necessity to simulate both the distribution network and the HHE. According to SCATER developer normally around 30 % of the energy should be provided by the distribution network, which confirms the design choices (Poulsen, 2023).

The calculated total length of the HHE is 44.3 km which is larger than the estimates from the NIRAS screening that assumes 30 km in total. The estimations in the NIRAS screening are based on 20 W/m heat absorption (NIRAS, 2023). The simulated network in Rårup has a heat absorption of 20 W/m in the peak situation on average, but slightly lower heat absorption at the HHE (17-18 W/m). This explains the difference in pipe length between the simulations and the NIRAS screening. The total area needed for both simulated heat exchangers is 4.43 hectares, which means that the heat exchanger cannot be placed in public areas only.

The detailed calculations for this chapter can be found as appendix D.

4.3 Comparison to different termonet scenarios

To find out if changing certain boundary conditions might benefit the case, additional scenarios were simulated.

4.3.1 Comparison to scenario with big consumers

In this scenario, two big consumers (>180 MWh/year, >100 kW daily load) at the pipe section N_Kirkedalsvej_E1 that initially were excluded were included. This scenario was then compared with the default scenario. The results for calculated pipe diameters are shown table 13 below. A map can be seen in appendix C.

	Default scenario (excl. big consumers)		Including big consumers		
Section name:	Pipe diameter [mm]	Reynolds nr.	Pipe diameter [mm]		Reynolds nr.
N_Main_Line	160	42856	160		58965
N_Kirkedalsvej_E1	**90**	18161	**110**	↑	26861
N_Kirkedalsvej_W1	160	33060	160		41210
N_Line_80	32	3643	32		3643
N_Aastrupvej	32	2429	32		2429
N_Flyvervaenget	63	10132	63		10132
N_Kirkedalsvej_W2	90	15926	90		15926
N_Glattrupvej	75	10621	75		10621
N_Bakkedalsvej	32	2429	32		2429
N_Sindballevej_1	90	18859	90		18859
N_Kirketoften	75	11932	75		11932
N_Sindballevej_2	75	10621	75		10621

Table 13: Comparison between including the big consumers and excluding the big consumers

Including the two big consumers results in increasing the pipe dimension at section N_Kirkedalsvej_E1 from 90 mm to 110 mm. At the same time the length of the HHE of the norther termonet is increased significantly by approximately 6 km (see table 14).

Scenario	Length of HHE in the northern part	Percentage provided by distribution net
Excluding two big consumers	22 400 m	33 %
Including two big consumers	28 560 m	28 %

Table 14: Comparison of HHE lengths in different scenarios

4.3.2 Comparison to scenario with higher pressure gradient

Distribution network

In this scenario, the pressure gradient was increased from 200 Pa/m to 300 Pa/m. This scenario was then compared with the initial scenario. The results for calculated pipe diameters are shown in tables 15,16 and figure 21 below.

North	**At 200 Pa/m**		**At 300 Pa/m**		
Section name:	Pipe diameter [mm]	Reynolds nr.	Pipe diameter [mm]		Reynolds nr.
N_Main_Line	160	42856	160		42856
N_Kirkedalsvej_E1	90	18161	90		18161
N_Kirkedalsvej_W1	**160**	33060	**125**	↓	42316
N_Line_80	32	3643	32		3643
N_Aastrupvej	**32**	2429	**25**	↓	3109
N_Flyvervaenget	63	10132	63		10132
N_Kirkedalsvej_W2	**90**	15926	**75**	↓	19111
N_Glattrupvej	**75**	10621	**63**	↓	12644
N_Bakkedalsvej	**32**	2429	**25**	↓	3109
N_Sindballevej_1	90	18859	90		18859
N_Kirketoften	**75**	11932	**63**	↓	14205
N_Sindballevej_2	**75**	10621	**63**	↓	12644

Table 15: Change of diameters and Reynolds numbers with different pressure gradients for the northern part

South	At 200 Pa/m		At 300 Pa/m		
Section name:	Pipe diameter [mm]	Reynolds nr	Pipe diameter [mm]		Reynolds nr
S_Main_Line	160	47019	160		47019
S_Bakkedalsvej_N1	**160**	35176	**125**	↓	45025
S_Bakkedalsvej_S1	**110**	20090	**90**	↓	24554
S_Ravnholtvej_1	**90**	15341	**75**	↓	18409
S_Moellebakken	63	9015	63		9015
S_Ravnholtvej_2	50	8124	50		8124
S_Bakkedalsvej_N2	110	24795	110		24795
S_Lillebaeksvej	63	12020	63		12020
S_Bakkedalsvej_N3	63	9492	63		9492
S_Smedegade	90	19886	90		19886
S_Bygaden	90	19504	90		19504

Table 16: Change of diameters and Reynolds numbers with different pressure gradients for the southern part

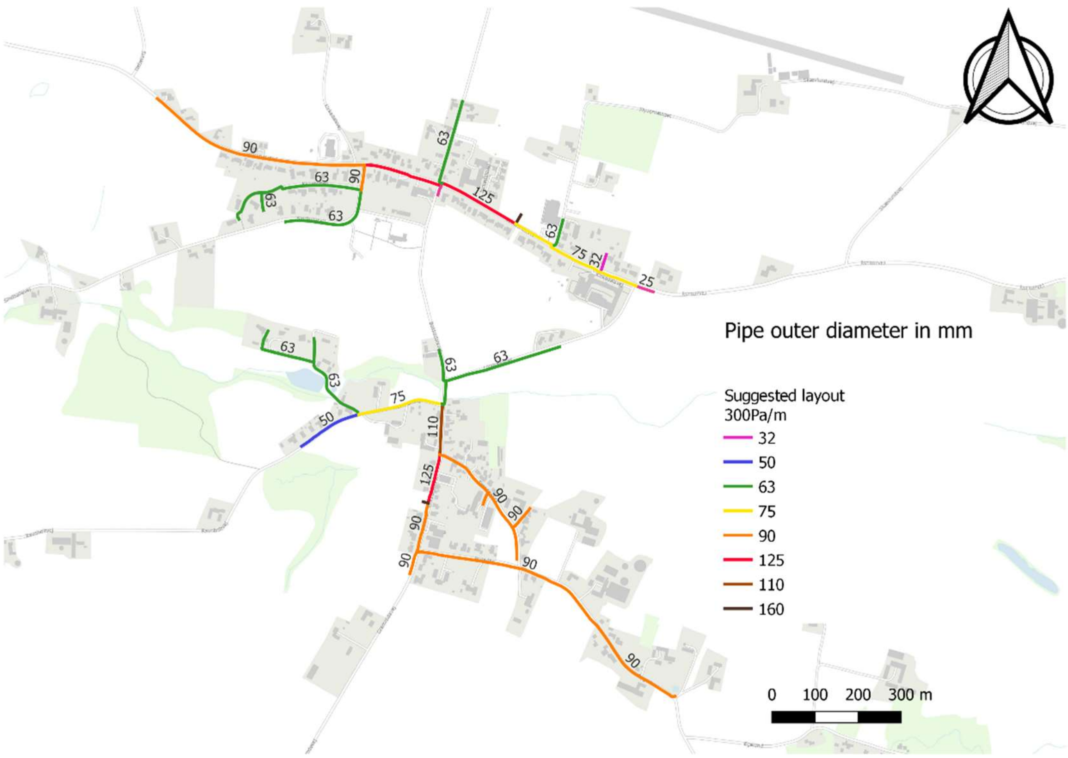

Figure 21: Suggested layout for the 300 Pa/m scenario for both parts

Table 17 below compares the existing gas pipe diameter with the simulated termonet pipe diameters for the default simulation (200 Pa/m) and the simulated termonet pipe diameters for the 300 Pa/m scenario. It can be seen that increasing the maximum pressure gradient from 200 Pa/m to 300 Pa/m results in smaller pipe dimensions needed at several sections. Sections where diameters changed are marked bold. Some of these sections therefore become compatible to needed termonet diameters.

Section name	Current Gas Diameter [mm]	200 Pa/m Scenario Diameter [mm]	300 Pa/m Scenario Diameter [m]	Is 200 Pa/m compatible?	Is 300 Pa/m compatible?
N_Åstrupvej	63	**32**	**25**	YES	YES
N_Bakkedalsvej	63	**32**	**25**	YES	YES
N_Flyvervaenget	63	63	63	YES	YES
N_Glattrupvej	63	**75**	**63**	NO	YES
N_Kirkedalsvej_E1	125	**90**	**75**	YES	YES
N_Kirkedalsvej_W1	125	**160**	**125**	NO	YES
N_Kirkedalsvej_W2	160	90	90	YES	YES
N_Kirketoften_2*	63	**75**	**63**	NO	YES
N_Kirketoften	63	**75**	**63**	NO	YES
N_Line_80	25	32	32	NO	NO
N_Sindballevej_1	63	90	90	NO	NO
N_Sindballevej_2	63	**75**	**63**	NO	YES
S_Bakkedalsvej_S1	90	**110**	**90**	NO	YES
S_Bakkedalsvej_N1	90	**160**	**125**	NO	NO
S_Bakkedalsvej_N2	90	110	110	NO	NO
S_Bakkedalsvej_N3	63	63	63	YES	YES
S_Bygaden	63	90	90	NO	NO
S_Bygaden_2*	63	90	90	NO	NO
S_Bygaden_3*	90	90	90	YES	YES
S_Lilliebaeksvej	125	63	63	YES	YES
S_Moellebakken	63	63	63	YES	YES
S_Møllebakken_2*	63	63	63	YES	YES
S_Ravnholtvej_1	63	**90**	**75**	NO	NO
S_Ravnholtvej_2	63	50	50	YES	YES
S_Smedegade	90	90	90	YES	YES
S_Smedegade_2*	25	90	90	NO	NO
S_Smedegade_3*	63	90	90	NO	NO

Table 17: Comparison of the pipe sizes between the existing network and simulation results

**These streets have separate sections in the existing gas network, but for the sake of simplicity, they were grouped into larger sections in the simulation*

Figure 22 below visualizes the results of the 300 Pa/m scenario in a map:

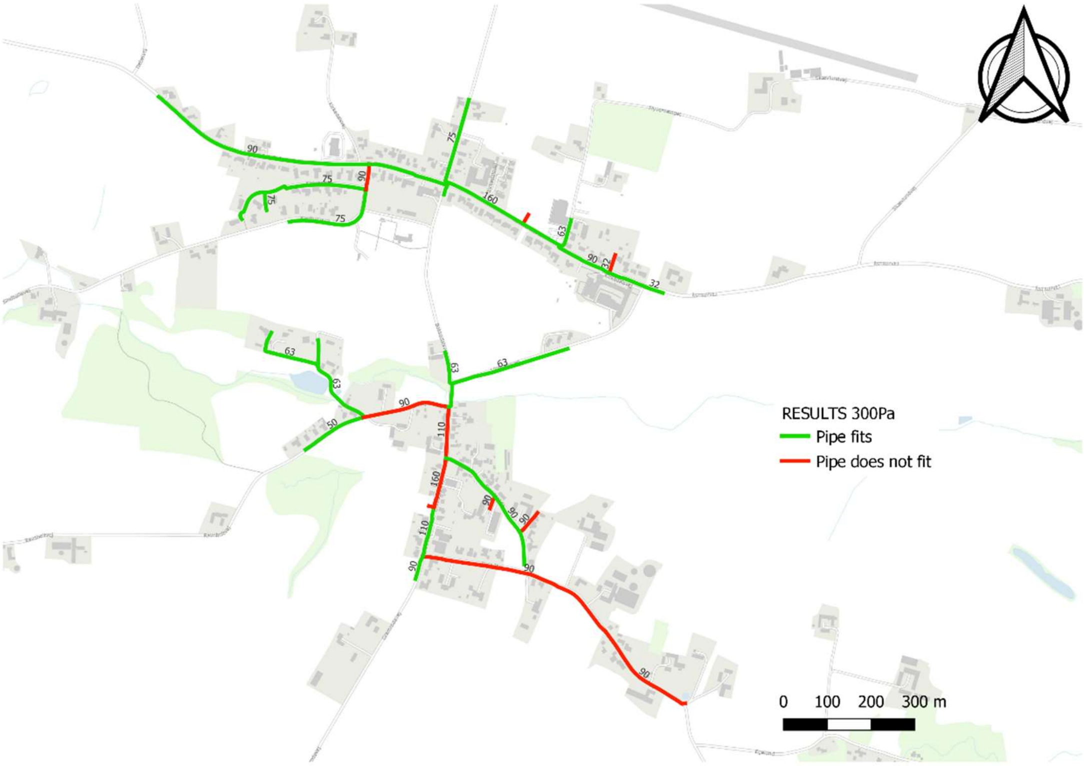

Figure 22: Comparison of the 300 Pa/m simulation to the existing gas network

Compared to the default scenario (200 Pa/m) 3629 m instead of 2315 m of gas pipes match required diameters in the 300 Pa/m scenario. Considering the condition of 1 m distance to drinking water pipes (as described in section 4.1.1) the utilized length increased from 2215 m to 3037 m only. This is because comparable many pipes that became suitable diameter wise are too close to drinking water pipes anyway.

	Length of gas pipes that fits the diameter	Length of gas pipes that fits the diameter and have at least 1 meter distance to DW pipes
At 200 Pa/m	2315 m	2215 m
At 300 Pa/m	3629 m	3037 m

Table 18: Length of gas pipes that fit the diameter in the simulation

Service pipes

The results for recalculated service pipe dimensions for specific consumer groups are shown in table 19 below. Here it can be observed that needed pipe dimensions decreased as well.

	At 200 Pa/m		At 300 Pa/m		
Service pipes	Pipe diameter [mm]	Reynolds nr.	Pipe diameter [mm]		Reynolds nr.
4kW	**32**	2429	**25**	↓	3109
6kW	32	3643	32		3643
8kW	40	3886	40		3886
10kW	40	4857	40		4857
12kW	**50**	4663	**40**	↓	5829
14kW	**50**	5440	**40**	↓	6800
16kW	50	6217	50		6217
18kW	50	6994	50		6994
20kW	50	7772	50		7772
26kW	**63**	8018	**50**	↓	10103
28kW	63	8635	63		8635
30kW	63	9252	63		9252

Table 19: Change of diameters and Reynolds numbers with different pressure gradients for the service pipes in the southern part

Horizontal heat exchanger

The size of the horizontal heat exchanger was not affected by changing the pressure gradient as it is dimensioned only after heat consumptions.

4.3.3 Comparison of different distribution pipe spacing

This simulation was performed to investigate the effect of different spacings between the supply and return line in the termonet. The ideal spacing between the supply and return line is often assumed to be 1 meter (Poulsen, 2023).

If the termonet would be constructed without using the existing gas network, it would be reasonable to place the pipes as close as possible, to minimize the cost for excavation and restoration of the pavement. If the gas network is reused, the spacing can be increased, as it does not affect the construction cost.

After creating the detailed drawing of the network including the LER-data, it was assumed that a realistic average spacing of 0.8 meters can be achieved in the entire network.

Table 20 below illustrates the required length of the HHE in the northern and southern part for the two different pipe spacings 0.4 and 0.8 meters.

	0.4 m spacing	0.8 m spacing
HHE length northern part	23 240 m	22 400 m
HHE length southern part	22 750 m	21 910 m
Total HHE length	45 990 m	44 310 m

Table 20: Comparison of the HHE length with different spacings

When decreasing the pipe spacing from 0.8 meters to 0.4 meters, the length of pipes in the HHE increases by 1680 meters. With the per meter price of 60 DKK/m of pipes in the HHE that was estimated in the NIRAS screening (NIRAS, 2023), the difference between the two scenarios is approximately 100 000 DKK.

The simulation of the SCATER software also provides the fraction of the overall heating energy that is provided by the distribution network (see table 21 below).

	0.4 m spacing	0.8 m spacing
Percentage provided by distribution net northern part	30 %	33 %
Percentage provided by distribution net southern part	31 %	34 %

Table 21: Comparison of the fraction of heat energy with different spacing

The difference of the spacings results in changes in approximately 3 percentage points.

4.3.4 Comparison of HHE to BHE

In this section the standard choice of HHE is compared with a borehole solution for the northern part of the network. As described in section 4.2.4 the HHE in the northern part of the network would need to have a total pipe length of 22 400 m and would cover 2.24 hectares.

With the input values described in section 3.5.5 the simulation was redone, using a borehole configuration. This is a brief simulation and the geology for deep ground source heating has not been investigated, so the result should be handled with caution.

The simulation showed that a cost optimized layout would be a 10 * 10 configuration with 100 boreholes. Each with a spacing of 15 meters in between both x and y axis. Each borehole would need to be drilled to a depth of 124 meters. The required area for the boreholes is 2.25 hectares. The maximum pressure loss in heating mode does not exceed 138 Pa/m while Reynolds number is 3858.

The borehole setup is expected to be more expensive and as there is sufficient space around Rårup to implement the HHE solution, the borehole solution is not investigated further.

5 Discussion

5.1 Including big consumers

Early in the process, it was decided to exclude two big consumers in the northern part. The reason behind it was that the big consumers might upscale the entire termonet and therefore harm the common benefit for all other consumers. Also, it was assumed that these consumers could have their own HHE, as they had available space in proximity. The simulations showed unexpectedly that the big consumers only had minor influence on the pipe sizes in the network. The size of the HHE on the other hand increased by 6 kilometers. This would affect the financial viability of the entire network, but at the same time the big consumers would provide a big additional upfront investment. These pros and cons need to be considered when deciding whether to include the big consumers in the final design phase.

5.2 Maximum pressure gradient

The calculation of pipe sizes is very dependent on the maximum pressure gradient allowed. As mentioned earlier, the recommended pressure gradient for ground source heat pump systems varies between 100 and 300 Pa/m. As the pressure gradient increases, pipe diameters can be reduced, but it also requires greater pumping power to overcome the pressure gradient. The main simulation case was performed with 200 Pa/m to leave space for additional single losses in the pipe network (valves, fittings etc.) that might increase the real pressure gradient anyway. But in particular it was chosen to aim for a middle value and keep a balance between needed pipe diameters and pumping power. As pipe diameters are already set by the existing gas pipes, the pressure gradient is the variable to change first. Hence, another simulation with 300 Pa/m as maximum pressure gradient was carried out. In that case, more pipes could be reused as needed pipe diameters decreased.

To conclude to what extent a compromise of lifting the maximum pressure gradient is feasible, detailed hydraulic calculations are needed. Hereby it must be considered that the simulation only represents the critical worst-case winter scenario and extra pumping power might only be needed for short periods.

5.3 Legislation

Further examination also needs to be done when it comes to the categorization of the termonet pipes. As mentioned before, a significant part of the existing gas network cannot be reused, as it does not meet the criteria for the minimum distance of 1 meter to the drinking water pipes. Rårup waterworks was contacted to determine their requirement for the minimum distance. The contact person referred to termonet as cold district heating and therefore the network needs to conform with the DS475 (Dansk Standard, 2015) norm and keep 1 meter distance.

The reason for 1 meter safety distance from water to district heating pipes is the heat loss into the ground and the risk of heating the drinking water. On the other hand, in wintertime there is a risk of freezing the ground and the water inside the drinking water pipes. Moreover, the district heating pipes need soil cover on all sides to prevent thermal expansion forces from deforming the pipes. Furthermore, soil is necessary to add friction to the district heating pipe, again to counteract the thermal expansion forces.

The temperatures in this termonet will normally be very similar to the ground temperature, as it is heated by the HHE and not by boreholes or other warmer heat sources. At the same time the temperature fluctuations are small in the network and hence the thermal forces. Therefore, it can be discussed whether the termonet pipes should be categorized as district heating pipes or as other pipe types as e.g., standard drinking water pipes. These subjects need further research and legislative decisions.

5.4 Financial viability of reusing the gas network

All financial calculations below are only for the investment in the distribution network without service pipes. As mentioned in section 4.2.4 all existing gas service pipes need to be replaced, as none fits the simulated pipe diameter. Furthermore, all calculations were performed without the additional cost of financing.

Calculations were made for either assuming construction by excavation only or by horizontal drilling only. However, in real life a combination of both technologies would likely take place. Therefore, results must be treated with caution.

5.4.1 Implementation of termonet by excavation

It is assumed that the cost for the pipes is 200 DKK per meter including joints and couplings. The investment for the pipes obviously varies according to diameter, but the 200 DKK is used as an average value (NIRAS).

The work and excavation costs were estimated to be 800 DKK per meter, including excavation, embedding, backfill, welding, reestablishing of pavement etc. A discount of quantity for buying the double number of pipes was neglected, as for the pipe manufacturers it normally is only a couple of percentages (Jochen tom Wörden, 2023).

It is assumed that the work and excavation costs can be reduced by 30 percent, when only laying one pipe. The fixed costs of renting the equipment and preparation are almost unchanged if one pipe is placed or two. The variable costs change as the number of weldings, the volume of the excavation and backfill and the area of pavement that needs to be restored changes (NIRAS, 2023) (Jochen tom Wörden, 2023). Table 22 below illustrates the costs per meter for each scenario.

	Two new pipes [DKK]	One new pipe (reusing gas pipes) [DKK]
Pipe material cost pr meter	400	200
Work cost per meter (Excavation, placement, welding etc.)	800	560
Total cost per meter	1200	760

Table 22: Excavation costs per 1m for the two scenarios

To get an estimation for the scenario, where the gas network is not reused, but two new pipes are placed in the entire network, the above-mentioned per meter costs are multiplied with the length of the distribution network (4970 m). Hence the cost of placing two new pipes in the network is 5 964 000 DKK (see appendix E). This figure will be compared to the cost of including the existing gas network in the new termonet.
As mentioned in section 4, the diameters of the existing gas network do not always fulfill the requirement that the SCATER software simulated for the termonet. Furthermore, there are sections of the existing gas network that are too close to the existing drinking water pipes. These stretches need to be replaced and the most cost-efficient way is to place two new pipes instead of changing the diameter of the existing one. The table below summarizes the length of gas pipes that can be reused in different scenarios.

	Length of gas pipes that fits the diameter	**Length of gas pipes that fits the diameter and have at least 1 meter distance to DW pipes**
At 200 Pa/m	2315 m	**2215 m**
At 300 Pa/m	3629 m	3037 m

Table 23: Comparison of the fitting pipes in the two scenarios

Using the per meter costs for laying respectively one and two pipes, these can be converted into network prices, see appendix E for the detailed calculations.

	Cost of gas pipes that fits the diameter	**Cost of gas pipes that fits the diameter and have at least 1 meter distance to DW pipes**
At 200 Pa/m	4 945 400 DKK	**4 989 400 DKK**
At 300 Pa/m	4 367 200 DKK	4 627 700 DKK

Table 24: Comparison of the two scenarios by price

The case for reusing the gas network is further improved by the shortened length of the HHE due to the bigger spacing between the pipes in the distribution network, as described earlier in section 4.3.3. On the other hand, there will be additional welding and excavation costs to connect the sections of the gas network to newly placed sections. It is assumed that these costs approximately outweigh each other.
The difference in lifetime of the newly placed pipes and the lifetime of the existing gas network is difficult to estimate. As mentioned in section 2.3.2 it can be assumed that the existing gas network can cope with another 50 years of operation. Due to the lack of better data, this report neglects the difference of lifetime from the financial calculations.

The main scenario used for the cost saving estimation was the one with 200 Pa/m design pressure gradient and satisfied 1 m distance to drinking water pipes (marked bold in table 24 above). Hence, the estimated cost difference between implementing 2 new termonet pipes and reusing gas pipes + implementing one new termonet pipe is approximately 975 000 DKK. This corresponds to 15 - 20 percent of the cost of the distribution network.

5.4.2 Implementation of termonet by directional drilling

The cost of directional drillings for this project has been carried out by using data from Vandprishåndbogen published in 2021 by DANVA (Danish Water and Wastewater Association) (DANVA, 2021).
The source provides the costs for PE pipes per 50 m of length, categorized into material cost, job cost, and equipment fee. The available diameter for directional drilling costs is between 90 mm and 200 mm. It was assumed that pipes smaller than 90 mm will be assigned the same cost. However, the prices could be different due to inflation and material costs for smaller pipes. The length was distributed into categories according to the diameter and associated costs for the work. Below in table 25, the summaries of lengths and costs can be seen.

	Northern network	Southern network
Length (one pipe)	2362 m	2608 m
Cost SUM (one pipe)	2 595 000 DKK	
Length (two pipes)	4724 m	5216 m
Cost SUM (two pipes)	5 190 000 DKK	

Table 25: Summary of the lengths and the prices for the northern and the southern network

The total cost for the northern and southern distribution network in the case of directional drilling was calculated to be 5 190 000 DKK. This is an estimate and does not include service pipes nor is it adjusted to inflation.

Based on the cost of the southern and northern distribution network, an average price per meter of 522 DKK was calculated. Table 26 below summarizes the length of gas pipes that can be reused in different scenarios.

	Length of gas pipes that fits the diameter	Length of gas pipes that fits the diameter and have at least 1 meter distance to DW pipes
At 200 Pa/m	2315 m	**2215 m**
At 300 Pa/m	3629 m	3037 m

Table 26: Comparison of the fitting pipes in the two scenarios

Using the per meter costs for laying pipes respectively, a conversion can be made into network prices. See appendix F for the detailed calculations.

	Cost of gas pipes that fits the diameter	Cost of gas pipes that fits the diameter and have at least 1 meter distance to DW pipes
At 200 Pa/m	3 980 300 DKK	**4 032 500 DKK**
At 300 Pa/m	3 294 300 DKK	3 462 500 DKK

Table 27: Comparison of the price of the two scenarios with the use of directional drilling

As with excavation, there are many uncertainties in the calculations for the directional drilling. However, the savings by using the gas network were calculated to be ~1 160 000 DKK. This corresponds to approximately 20-25 percent of the cost of the distribution network.
In addition to that, it must be noted that the drilling mud around the pipes might affect the geothermal soil properties and therefore change the required length and costs of the supplementary heat exchanger as heat gain trough the distribution network changes.

5.5 Further investigation into unknown factors

5.5.1 Material science and hydraulics

Regarding the termonet, pipe diameters and Reynolds numbers were calculated. Further hydraulic properties as supply and return pressure, pressure gradient, velocity and actual pressure gradient were not calculated. In a termonet the pressure to circulate the brine in the system comes from circulation pumps at the individual heat pumps at the consumers. If these cannot provide enough pressure, extra circulation pumps are needed. As there are 122 circulation pumps, one at each consumer heat pump that run at different times and with different power, it is hard to formulate precise hydraulic calculations for the termonet. The attempt to make rough calculations was made but due to the lack of resources, this part was not further investigated. Henceforth, no statements about the forementioned hydraulic properties can be made. Most of the gas network installation is rated to 2.5 bars pressure which seems too low for termonet. Assuming the rated pressure cannot be increased, operating pressures might be too high for the existing gas pipes.

5.5.2 Legislation

Since termonet is a relatively new concept, legislation does not set boundaries as specific as for the other infrastructure. It is important, that decision makers re-assess possible risks, but also possible unnecessary restrictions with the upcoming interest in the project. Since termonet is considered “cold district heating” on a legislative level, the spacing between termonet pipes and drinking water pipes must be the same as for the conventional district heating. The temperature the termonet operates at is on average lower, or the same as the drinking water pipes. Therefore, the energy transfer should not be as problematic, and the pipes might be laid closer to the drinking water pipes. On the other hand, the brine contains alcohol, which might be more problematic than conventional district heating when it comes to leakage.

Additionally, even though the termonet pipes and gas pipes are both plastic PE type, they are manufactured according to different standards. Hence, further investigation is required to determine if it is necessary to recertificate the gas pipes for termonet use.

5.5.3 Heat exchanger placement

As written in chapter 3.4.3, the heat exchanger was placed based on central location, access to suitable gas distribution pipes and available area. However, at the time of writing the report no official location for the placement was chosen. The findings in the results show that the gas network is partly usable, meaning that several sections would need higher diameter pipes. A possibility could be to divide the project area into smaller single termonet, each with their own HHE. Further sectioning could decentralize the heat gain over the whole project area and potentially create the opportunity to use smaller distribution pipes and therefore utilize more gas pipes. However, this is purely a theoretical assumption and further investigations would need to be done.

6 Conclusions

This project case includes 122 households in Rårup that currently are heated with natural gas and oil. The total annual heating demand is 1860.3 MWh and the maximum daily peak load is 1182 kW. Based on derived consumption patterns and geological conditions, the termonet was divided into a northern and a southern system. These two termonet were then dimensioned by the SCATER software to compare if gas pipe dimensions are compatible.

It was found that approximately 2.2 km of the existing gas network can be reused for the upcoming termonet, corresponding to 44.6 % of the existing gas network. This leads to cost savings of 975 000 DKK to 1 160 000 DKK which corresponds to around 20 % of the construction cost of the distribution network. The existing service pipes are not suitable for the termonet and therefore cannot contribute to the savings.

The amount of reutilized gas pipes and hence the savings could be increased if certain boundary conditions such as pressure gradient or pipe classification could be changed. Also, distributing the two 22 km long HHEs could make the termonet more suitable for gas pipe reuse.

To make a fully qualified statement whether the gas pipes can be reutilized, further hydraulic calculations about pressure properties must be performed. Also, the legislation and approval of using the gas pipe for brine by the municipality is still an issue to overcome.

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Assessment of gas pipe reuse for termonet in Rårup

Appendix A

Students:

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Supervisor:

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In cooperation with:

NIRAS

Climate and Supply Engineering

6. Semester

01.06.2023

Heat pump ID	Yearly heating load (W)	Winter heating load (W)	Daily heating load (W)	Year COP	Winter COP	Hour COP	dT HP heating	Yearly cooling demand (W)	Summer cooling load (W)	Daily cooling load (W)	EER	dt HP cooling
A	49	78	4000	3.6	3.6	3	3	0	100	100	25	4
B	102	162	4000	3.6	3.6	3	3	0	100	100	25	4
C	231	369	4000	3.6	3.6	3	3	0	100	100	25	4
D	282	451	4000	3.6	3.6	3	3	0	100	100	25	4
E	318	508	4000	3.6	3.6	3	3	0	100	100	25	4
F	399	639	4000	3.6	3.6	3	3	0	100	100	25	4
G	447	715	4000	3.6	3.6	3	3	0	100	100	25	4
H	515	825	4000	3.6	3.6	3	3	0	100	100	25	4
I	616	985	4000	3.6	3.6	3	3	0	100	100	25	4
J	659	1055	4000	3.6	3.6	3	3	0	100	100	25	4
K	670	1072	4000	3.6	3.6	3	3	0	100	100	25	4
L	671	1074	4000	3.6	3.6	3	3	0	100	100	25	4
M	705	1129	4000	3.6	3.6	3	3	0	100	100	25	4
N	712	1139	4000	3.6	3.6	3	3	0	100	100	25	4
O	719	1150	4000	3.6	3.6	3	3	0	100	100	25	4
P	748	1196	4000	3.6	3.6	3	3	0	100	100	25	4
Q	774	1238	4000	3.6	3.6	3	3	0	100	100	25	4
R	836	1337	6000	3.6	3.6	3	3	0	100	100	25	4
S	852	1363	6000	3.6	3.6	3	3	0	100	100	25	4
T	864	1382	6000	3.6	3.6	3	3	0	100	100	25	4
U	874	1399	6000	3.6	3.6	3	3	0	100	100	25	4
V	874	1399	6000	3.6	3.6	3	3	0	100	100	25	4
W	902	1443	6000	3.6	3.6	3	3	0	100	100	25	4
X	956	1529	6000	3.6	3.6	3	3	0	100	100	25	4
Y	958	1534	6000	3.6	3.6	3	3	0	100	100	25	4
Z	977	1563	6000	3.6	3.6	3	3	0	100	100	25	4
AA	986	1578	6000	3.6	3.6	3	3	0	100	100	25	4
AB	993	1588	6000	3.6	3.6	3	3	0	100	100	25	4
AC	1005	1607	6000	3.6	3.6	3	3	0	100	100	25	4
AD	1013	1620	6000	3.6	3.6	3	3	0	100	100	25	4
AE	1020	1633	6000	3.6	3.6	3	3	0	100	100	25	4
AF	1038	1660	6000	3.6	3.6	3	3	0	100	100	25	4
AG	1053	1685	6000	3.6	3.6	3	3	0	100	100	25	4
AH	1055	1688	6000	3.6	3.6	3	3	0	100	100	25	4
AI	1060	1696	6000	3.6	3.6	3	3	0	100	100	25	4
AJ	1069	1711	6000	3.6	3.6	3	3	0	100	100	25	4
AK	1071	1713	6000	3.6	3.6	3	3	0	100	100	25	4
AL	1107	1772	6000	3.6	3.6	3	3	0	100	100	25	4
AM	1123	1797	6000	3.6	3.6	3	3	0	100	100	25	4
AN	1129	1807	6000	3.6	3.6	3	3	0	100	100	25	4
AO	1147	1835	6000	3.6	3.6	3	3	0	100	100	25	4
AP	1175	1880	6000	3.6	3.6	3	3	0	100	100	25	4
AQ	1181	1890	6000	3.6	3.6	3	3	0	100	100	25	4
AR	1245	1991	8000	3.6	3.6	3	3	0	100	100	25	4
AS	1271	2033	8000	3.6	3.6	3	3	0	100	100	25	4
AT	1314	2103	8000	3.6	3.6	3	3	0	100	100	25	4
AU	1314	2103	8000	3.6	3.6	3	3	0	100	100	25	4
AV	1336	2137	8000	3.6	3.6	3	3	0	100	100	25	4
AW	1342	2147	8000	3.6	3.6	3	3	0	100	100	25	4
AX	1362	2179	8000	3.6	3.6	3	3	0	100	100	25	4
AY	1383	2213	8000	3.6	3.6	3	3	0	100	100	25	4
AZ	1417	2268	8000	3.6	3.6	3	3	0	100	100	25	4
BA	1424	2278	8000	3.6	3.6	3	3	0	100	100	25	4
BB	1428	2285	8000	3.6	3.6	3	3	0	100	100	25	4
BC	1432	2290	8000	3.6	3.6	3	3	0	100	100	25	4
BD	1432	2292	8000	3.6	3.6	3	3	0	100	100	25	4
BE	1437	2299	8000	3.6	3.6	3	3	0	100	100	25	4
BF	1450	2320	8000	3.6	3.6	3	3	0	100	100	25	4

BG	1479	2367	8000	3.6	3.6	3	3	0	100	100	25	4
BH	1510	2415	8000	3.6	3.6	3	3	0	100	100	25	4
BI	1514	2422	8000	3.6	3.6	3	3	0	100	100	25	4
BJ	1574	2519	8000	3.6	3.6	3	3	0	100	100	25	4
BK	1614	2582	8000	3.6	3.6	3	3	0	100	100	25	4
BL	1618	2588	8000	3.6	3.6	3	3	0	100	100	25	4
BM	1620	2592	8000	3.6	3.6	3	3	0	100	100	25	4
BN	1628	2605	8000	3.6	3.6	3	3	0	100	100	25	4
BO	1647	2636	10000	3.6	3.6	3	3	0	100	100	25	4
BP	1648	2637	10000	3.6	3.6	3	3	0	100	100	25	4
BQ	1655	2647	10000	3.6	3.6	3	3	0	100	100	25	4
BR	1656	2649	10000	3.6	3.6	3	3	0	100	100	25	4
BS	1678	2685	10000	3.6	3.6	3	3	0	100	100	25	4
BT	1680	2687	10000	3.6	3.6	3	3	0	100	100	25	4
U	1689	2703	10000	3.6	3.6	3	3	0	100	100	25	4
BV	1697	2715	10000	3.6	3.6	3	3	0	100	100	25	4
BW	1728	2765	10000	3.6	3.6	3	3	0	100	100	25	4
BX	1733	2773	10000	3.6	3.6	3	3	0	100	100	25	4
BY	1754	2807	10000	3.6	3.6	3	3	0	100	100	25	4
BZ	1792	2867	10000	3.6	3.6	3	3	0	100	100	25	4
CA	1799	2879	10000	3.6	3.6	3	3	0	100	100	25	4
CB	1813	2900	10000	3.6	3.6	3	3	0	100	100	25	4
CC	1813	2900	10000	3.6	3.6	3	3	0	100	100	25	4
CD	1827	2924	10000	3.6	3.6	3	3	0	100	100	25	4
CE	1844	2951	10000	3.6	3.6	3	3	0	100	100	25	4
CF	1847	2955	10000	3.6	3.6	3	3	0	100	100	25	4
CG	1851	2962	10000	3.6	3.6	3	3	0	100	100	25	4
CH	1880	3007	10000	3.6	3.6	3	3	0	100	100	25	4
CI	1901	3041	10000	3.6	3.6	3	3	0	100	100	25	4
CJ	1902	3044	10000	3.6	3.6	3	3	0	100	100	25	4
CK	1946	3114	10000	3.6	3.6	3	3	0	100	100	25	4
CL	1968	3149	10000	3.6	3.6	3	3	0	100	100	25	4
CM	1992	3187	10000	3.6	3.6	3	3	0	100	100	25	4
CN	2008	3213	10000	3.6	3.6	3	3	0	100	100	25	4
CO	2093	3348	12000	3.6	3.6	3	3	0	100	100	25	4
CP	2123	3396	12000	3.6	3.6	3	3	0	100	100	25	4
CQ	2134	3415	12000	3.6	3.6	3	3	0	100	100	25	4
CR	2136	3418	12000	3.6	3.6	3	3	0	100	100	25	4
CS	2141	3426	12000	3.6	3.6	3	3	0	100	100	25	4
CT	2152	3443	12000	3.6	3.6	3	3	0	100	100	25	4
CU	2152	3443	12000	3.6	3.6	3	3	0	100	100	25	4
CV	2165	3464	12000	3.6	3.6	3	3	0	100	100	25	4
CW	2169	3470	12000	3.6	3.6	3	3	0	100	100	25	4
CX	2195	3512	12000	3.6	3.6	3	3	0	100	100	25	4
CY	2233	3573	12000	3.6	3.6	3	3	0	100	100	25	4
CZ	2240	3584	12000	3.6	3.6	3	3	0	100	100	25	4
DA	2494	3991	14000	3.6	3.6	3	3	0	100	100	25	4
DB	2746	4394	14000	3.6	3.6	3	3	0	100	100	25	4
DC	2845	4552	14000	3.6	3.6	3	3	0	100	100	25	4
DD	2853	4565	14000	3.6	3.6	3	3	0	100	100	25	4
DE	2884	4615	16000	3.6	3.6	3	3	0	100	100	25	4
DF	2952	4723	16000	3.6	3.6	3	3	0	100	100	25	4
DG	2987	4780	16000	3.6	3.6	3	3	0	100	100	25	4
DH	3462	5539	18000	3.6	3.6	3	3	0	100	100	25	4
DI	3569	5710	18000	3.6	3.6	3	3	0	100	100	25	4
DJ	3709	5934	20000	3.6	3.6	3	3	0	100	100	25	4
DK	3823	6117	20000	3.6	3.6	3	3	0	100	100	25	4
DL	3891	6226	20000	3.6	3.6	3	3	0	100	100	25	4
DM	4964	7942	26000	3.6	3.6	3	3	0	100	100	25	4
DN	5498	8796	28000	3.6	3.6	3	3	0	100	100	25	4
DO	5564	8902	28000	3.6	3.6	3	3	0	100	100	25	4
DP	5744	9191	28000	3.6	3.6	3	3	0	100	100	25	4

DQ	5789	9263	30000	3.6	3.6	3	3	0	100	100	25	4
DR	5836	9337	30000	3.6	3.6	3	3	0	100	100	25	4
DS	21490	34384	105000	3.6	3.6	3	3	0	100	100	25	4
DT	21847	34955	107000	3.6	3.6	3	3	0	100	100	25	4

Assessment of gas pipe reuse for termonet in Rårup

Appendix B

Students:

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In cooperation with:

NIRAS

Climate and Supply Engineering

6. Semester

01.06.2023

APPENDIX B- Topology

NORTH

Section	SDR	Trace_(m)	Number_of_traces	HP_ID_vector
N_Main_Line	17	1	1	56,57,58,59,60,61,62,63,64,65,66,67,69,73,74,75,76,78,79,68,81,51,50,48,77,82,47,49,93,94,52,53,55,89,87,85,95,86,84,92,90,83,91,80,109,114,113,112,111,110,88,54,19,42,43,44,45,41,40,72,39,38,37,1,71,70
N_Kirkedalsvej_E1	17	446	1	73,75,72,70,38,39,37,74,76,78,80,79,1,71
N_Kirkedalsvej_W1	17	375	1	56,57,58,59,60,61,62,63,64,65,66,67,69,68,81,51,50,48,77,82,47,49,93,94,52,53,55,89,87,85,95,86,84,92,90,83,91,109,114,113,112,111,110,88,54,19,42,43,44,45,41,40
N_Line_80	17	44	1	80
N_Aastrupvej	17	42	1	1
N_Flyvervaenget	17	71	1	37,38,39
N_Kirkedalsvej_W2	17	528	1	68,81,51,50,48,77,82,47,49,93,94,52,53,55
N_Glattrupvej	17	207	1	41,40,45,43,44,42
N_Bakkedalsvej	17	32	1	19
N_Sindballevej_1	17	60	1	89,87,85,95,92,90,83,88,54,109,114,113,112,111,110,91,84
N_Kirketoften	17	327	1	91,83,90,92,84,86,95,85,87,89
N_Sindballevej_2	17	229	1	109,114,113,112,111,110
4kW	17	20	9	1,19,49,66,73,76,87,90,95
6kW	17	20	17	38,48,58,59,64,68,69,80,82,85,88,89,91,92,93,94,109
8kW	17	20	13	37,42,51,52,55,56,60,65,74,78,111,113,114
10kW	17	20	12	40,41,43,44,50,54,62,72,81,84,86,112
12kW	17	20	7	45,47,53,63,75,77,79
14kW	17	20	1	83
16kW	17	20	1	57
18kW	17	20	1	70
20kW	17	20	2	61,110
30kW	17	20	1	39
105kW	17	20	1	71
107kW	17	20	1	67

SOUTH

Section	SDR	Trace_(m)	Number_o	HP_ID_vector
S_Main_Line	17	45	1	2,3,4,5,6,7,8,9,10,11,12,13,14,17,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,46,115,116,117,118,119,120,121,122,123,124,15,16,18,96,97,98,99,100,101,102,103,104,105,106,107,108
S_Bakkedalsvej_N1	17	120	1	3,4,6,7,8,9,10,11,13,14,15,16,17,18,22,25,96,97,98,99,100,101,102,103,104,105,106,107,108,115,116,117,118,119,120,121,122,123,124
S_Bakkedalsvej_S1	17	110	1	2,5,12,20,21,23,24,26,27,28,29,30,31,32,33,34,35,36,46,25
S_Ravnholtvej_1	17	170	1	99, 100,101,102,103,104,105,106,107,108
S_Moellebakken	17	385	1	99,100,101,102,107
S_Ravnholtvej_2	17	150	1	104,105,108
S_Bakkedalsvej_N2	17	152	1	8,10,13,14,15,16,17,18,96,97,98,99,100,101,102,103,104,105,106,107,108
S_Lillebaeksvej	17	420	1	15,16,96,97,98
S_Bakkedalsvej_N3	17	71	1	15,16
S_Smedegade	17	320	1	115,116,117,118,119,120,121,122,123,124
S_Bygaden	17	710	1	23,24,26,27,28,29,30,31,32,33,34,35,36,46,25
4kW	17	20	8	8,13,20,34,35,98,101,122
6kW	17	20	9	2,3,5,11,28,29,97,107,117
8kW	17	20	10	9,26,30,36,96,99,104,108,120,123
10kW	17	20	14	4,6,10,15,17,21,23,31,32,33,46,100,103,118
12kW	17	20	5	12,18,24,105,124
14kW	17	20	3	22,27,102
16kW	17	20	2	14,121
18kW	17	20	1	115
20kW	17	20	1	25
26kW	17	20	1	7
28kW	17	20	3	16,106,116
30kW	17	20	1	119

Assessment of gas pipe reuse for termonet in Rårup

Appendix C

Students:

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Supervisor:

Carsten Nielsen **CARN**

In cooperation with:

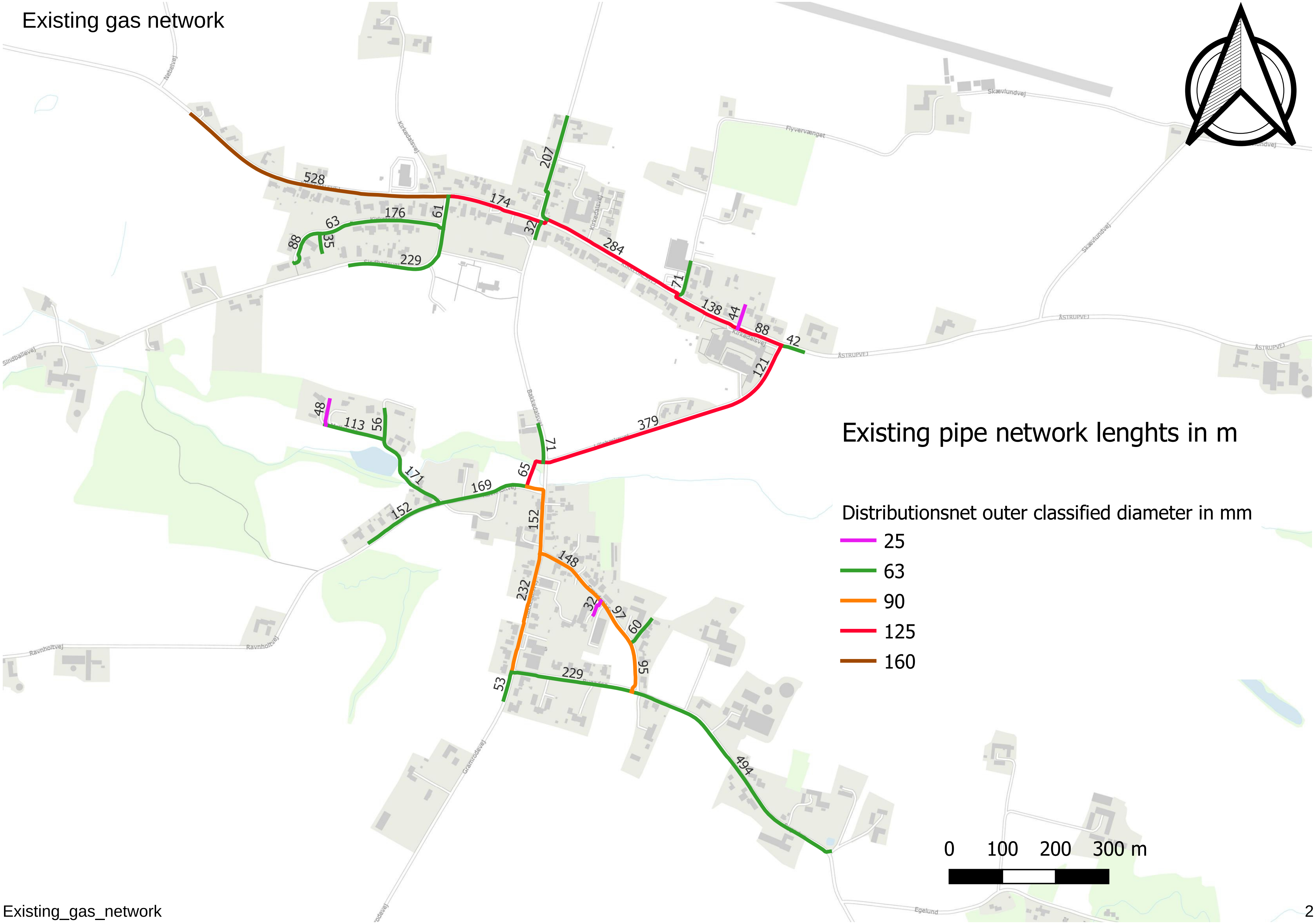
NIRAS

Climate and Supply Engineering

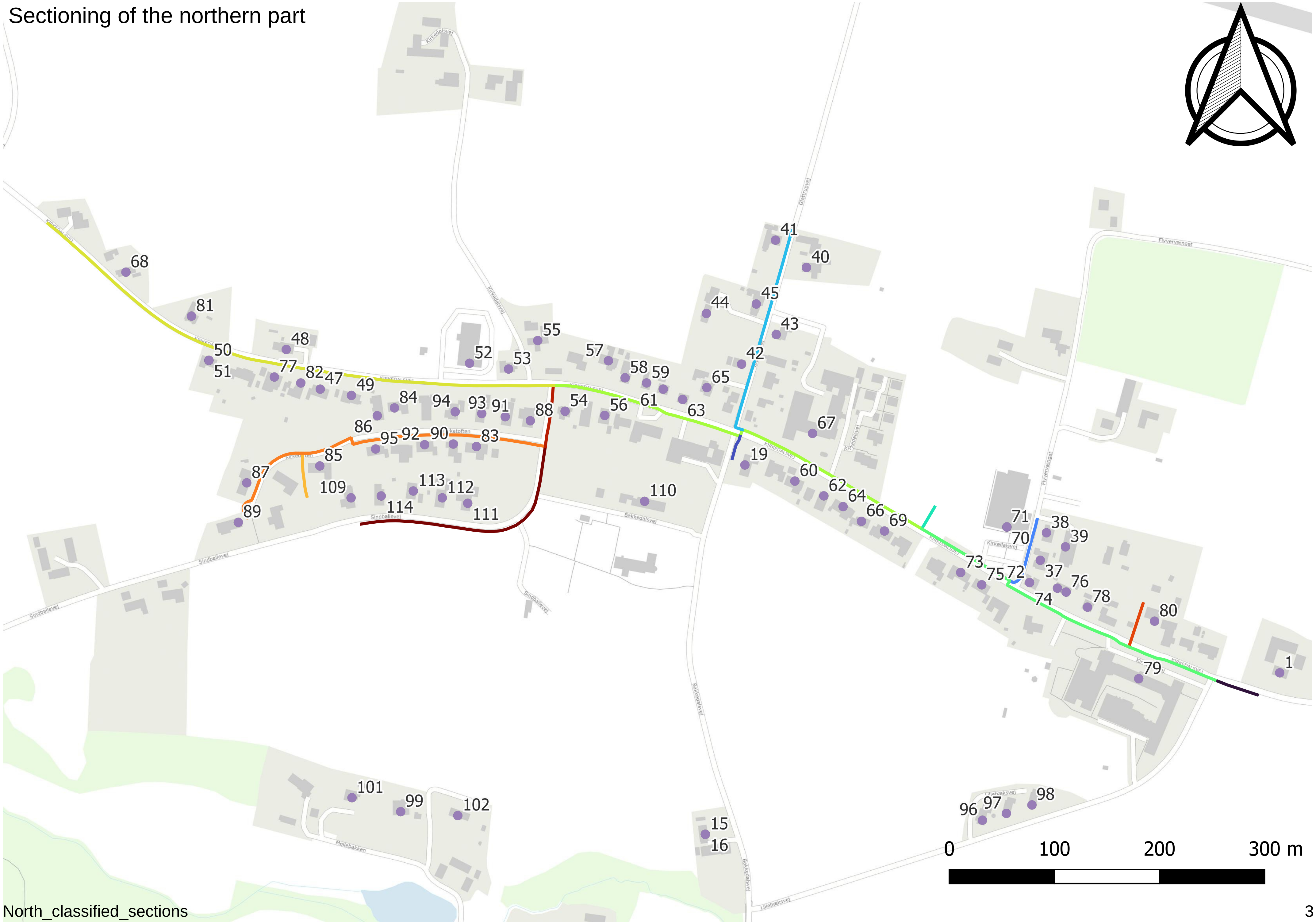
6. Semester

01.06.2023

Existing gas network

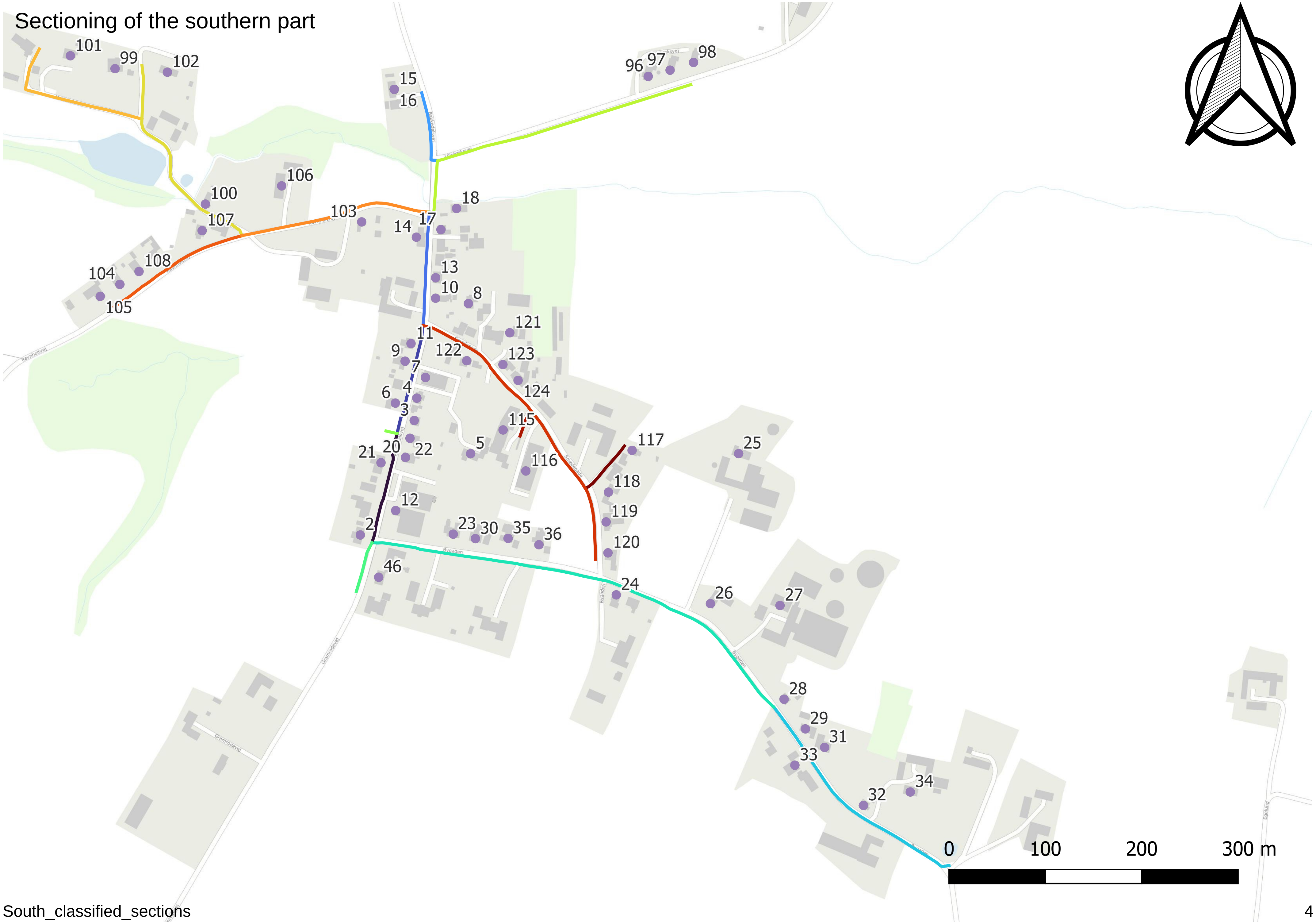


Sectioning of the northern part

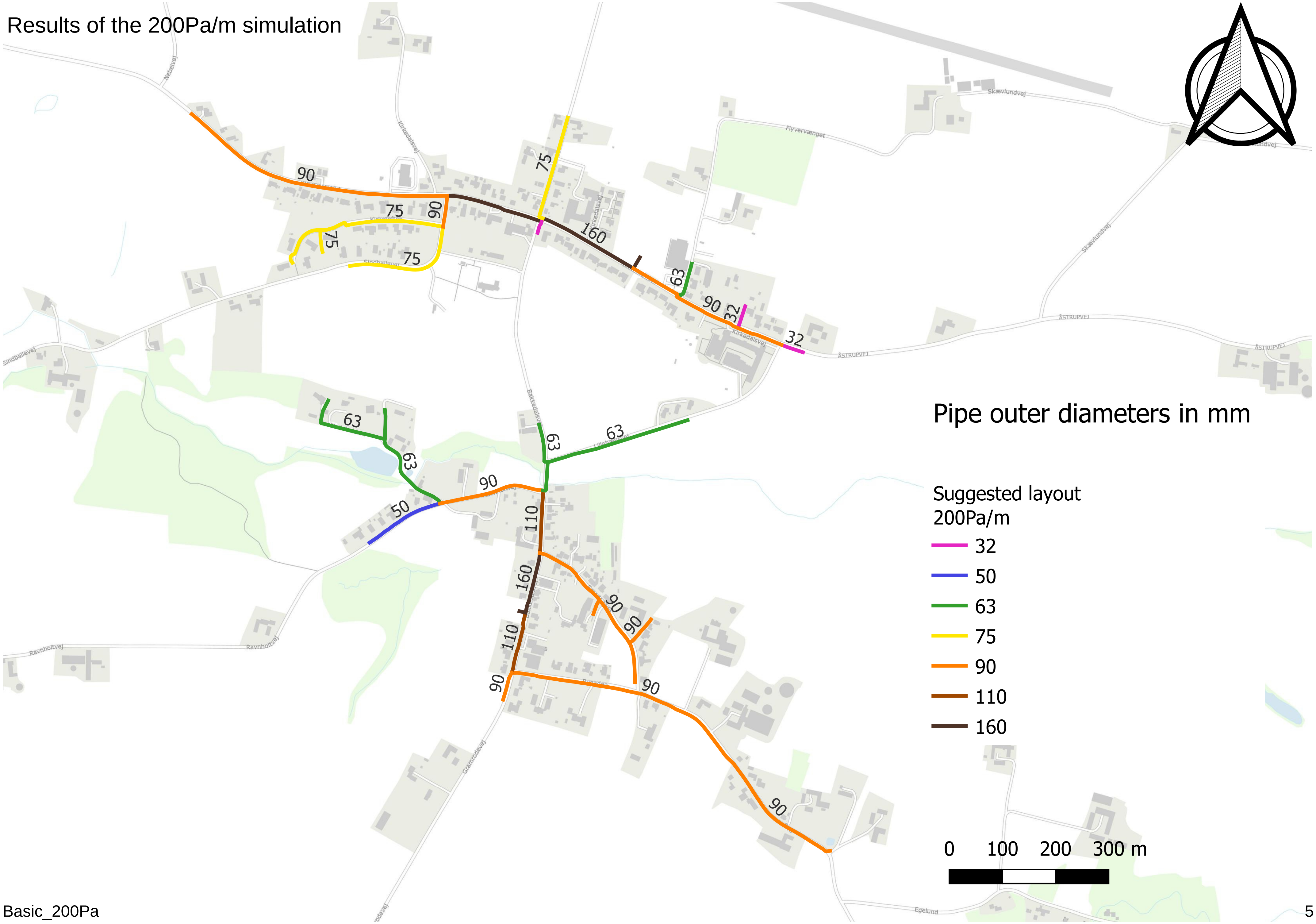


North_classified_sections

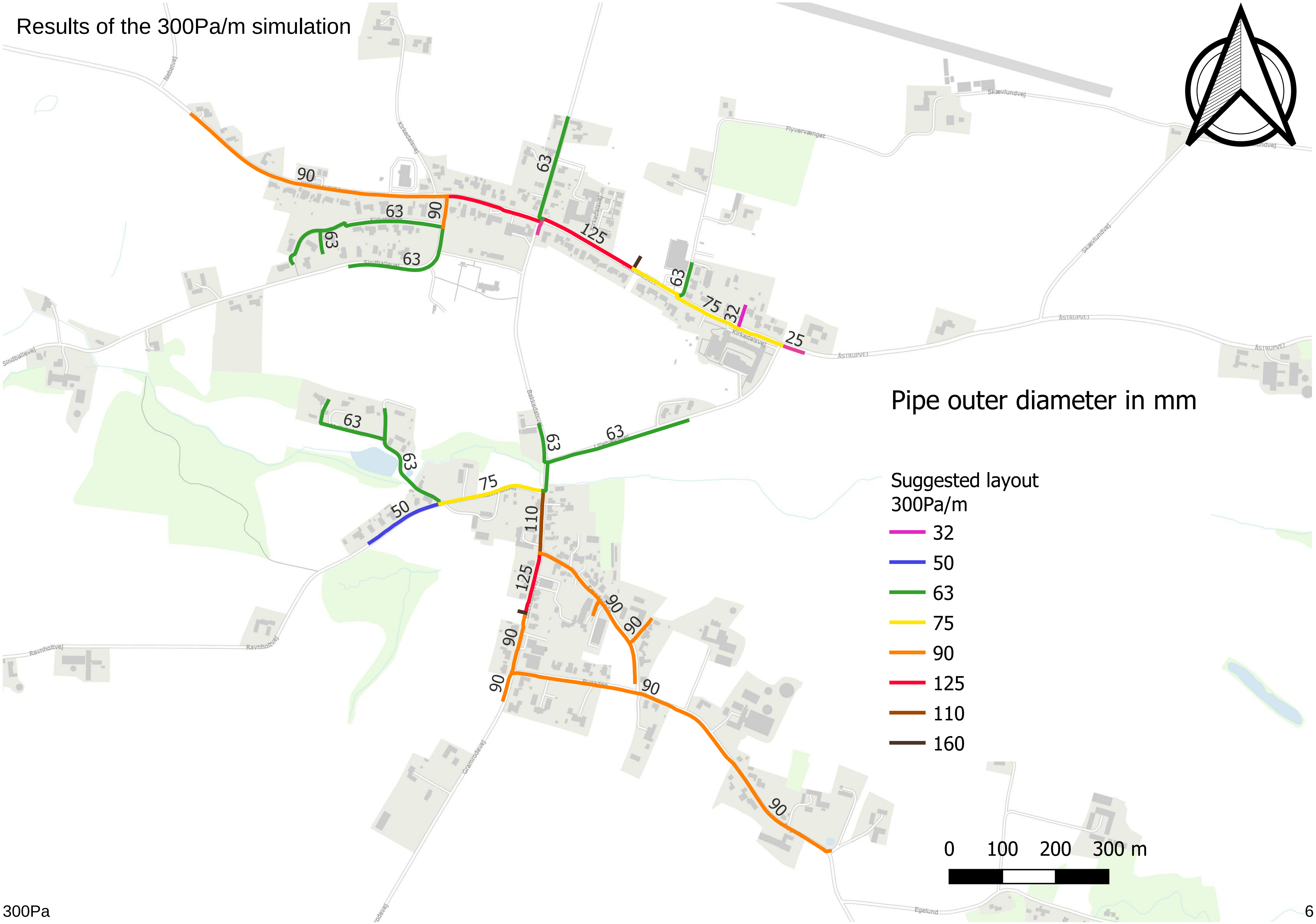
Sectioning of the southern part



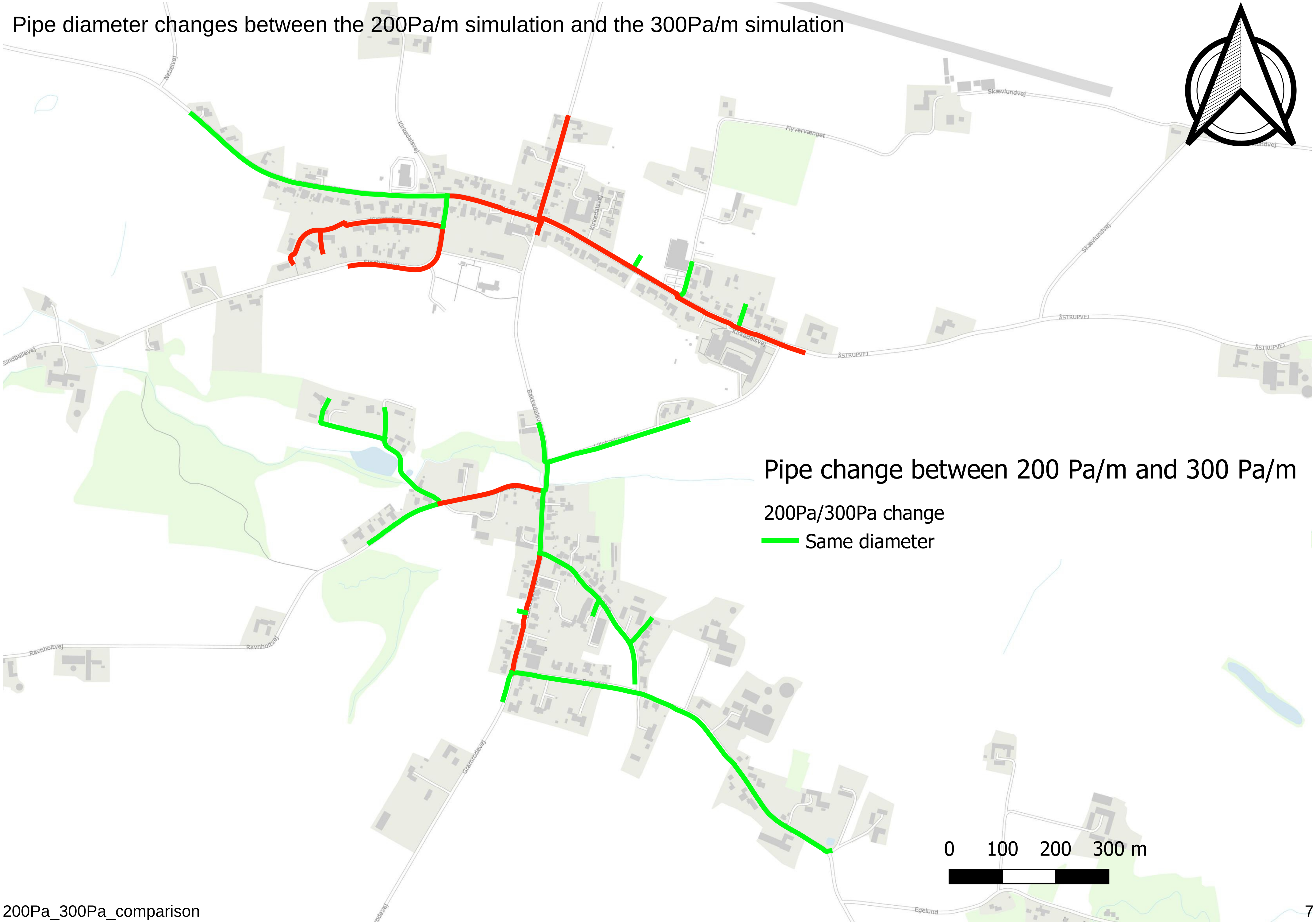
Results of the 200Pa/m simulation



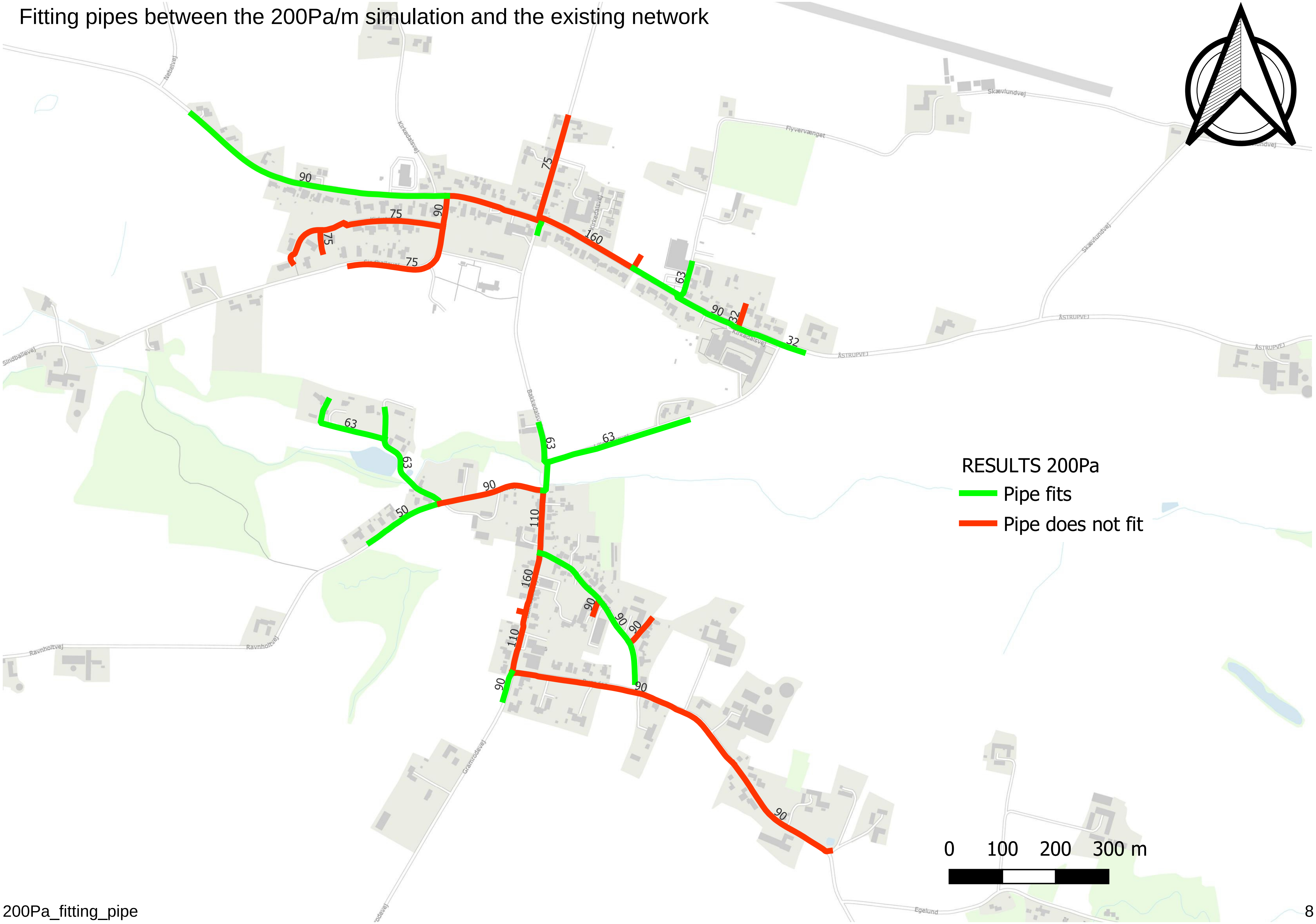
Results of the 300Pa/m simulation



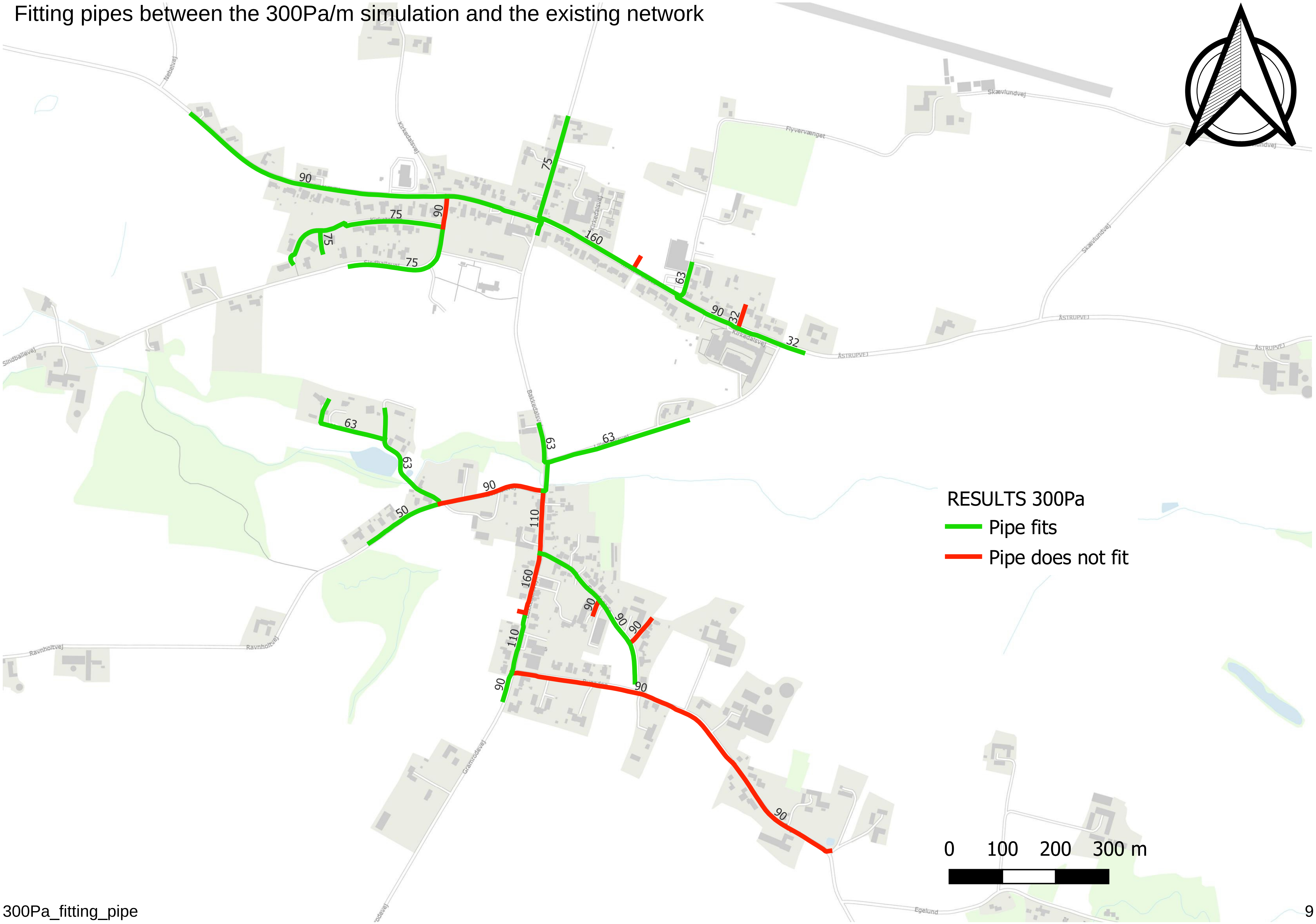
Pipe diameter changes between the 200Pa/m simulation and the 300Pa/m simulation



Fitting pipes between the 200Pa/m simulation and the existing network



Fitting pipes between the 300Pa/m simulation and the existing network



Assessment of gas pipe reuse for termonet in Rårup

Appendix D

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In cooperation with:

NIRAS

Climate and Supply Engineering

6. Semester

01.06.2023

Appendix D - Calculations HHE

North

Input values from the dimensioning software

$n_{loops} := 70 \qquad spacing := 1\ m \qquad EachLoop_{Length} := 320\ m$

$area := n_{loops} \cdot spacing \cdot EachLoop_{Length} \quad area = 2.24\ hectare \qquad area = 0.0224\ km^2$

The length of the network including service pipes

$Length_{Network} := 3642\ m \cdot 2 = 7284\ m$

$Length_{Groundloop} := n_{loops} \cdot EachLoop_{Length} = 22400\ m$

Total length of the network and the ground loops

$Length_{Total} := Length_{Network} + Length_{Groundloop} = 29684\ m$

The peak heat demand in the network until 30 kw consumer

$Heating := 564\ kW$

Energy provided by the soil

$$Soil := \frac{Heating}{Length_{Total}} = 19.0001\ \frac{W}{m}$$

South

Input values from the dimensioning software

$n_{loops\_south} := 70 \qquad spacing_{south} := 1\ m \qquad EachLoop_{Length\_south} := 313\ m$

$area_{south} := n_{loops\_south} \cdot spacing_{south} \cdot EachLoop_{Length\_south} \qquad area_{south} = 2.191\ hectare$

The length of the network including service pipes

$Length_{Network\_south} := 3813\ m \cdot 2 = 7626\ m$

$Length_{Groundloop\_south} := n_{loops\_south} \cdot EachLoop_{Length\_south} = 21910\ m$

Total length of the network and the ground loops

$Length_{Total\_south} := Length_{Network\_south} + Length_{Groundloop\_south} = 29536\ m$

The peak heat demand in the network

$$Heating_{south} := 618\ kW$$

Energy provided by the soil

$$Soil_{south} := \frac{Heating_{south}}{Length_{Total\_south}} = 20.9236\ \frac{W}{m}$$

Average value for energy by distribution network

$$\frac{564\ kW + 618\ kW}{29684\ m + 29536\ m} = 19.9595\ \frac{W}{m}$$

Area needed for the boreholes

$$(10 \cdot 15\ m) \cdot (10 \cdot 15\ m) = 2.25\ hectare$$

Assessment of gas pipe reuse for termonet in Rårup

Appendix E

Students:

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Matej Grego	**305656**
Mikkel Lorenz	**304868**
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Supervisor:

Carsten Nielsen **CARN**

In cooperation with:

NIRAS

Climate and Supply Engineering

6. Semester

01.06.2023

Appendix E: Estimation of the excavation cost

$DKK := ¤$

Pipe material costs per meter

$$Pipes := 200 \frac{DKK}{m}$$

Cost of the work (Excavation, placement, welding etc) for placing two pipes

$$Work := 800 \frac{DKK}{m}$$

Length of the network

$$Length_{Network} := 2362\ m + 2608\ m = 4970\ m$$

Pripe per meter for placing two new pipes

$$Lbm_{TwoPipes} := Pipes \cdot 2 + Work = 1200 \frac{DKK}{m}$$

Pripe per meter for placing one new pipe and utilize the existing gas network

$$Lbm_{OnePipe} := Pipes + Work \cdot 0.7 = 760 \frac{DKK}{m}$$

Total initial cost of placing two new pipes for the entire network:

$$Cost_{New} := Lbm_{TwoPipes} \cdot Length_{Network} = 5964000\ DKK$$

The stretches of the gas network, where the diameter is too small, needs to be replaced. In these section two new pipes are placed.

At 200 Pa/m

$$Length_{Reused} := 2315\ m$$

$$Length_{OnePipe} := Length_{Reused} = 2315\ m$$

$$Length_{TwoPipes} := Length_{Network} - Length_{Reused} = 2655\ m$$

$$Cost_{Network\_Small\_Diameter} := Lbm_{OnePipe} \cdot Length_{OnePipe} + Lbm_{TwoPipes} \cdot Length_{TwoPipes}$$

$$Cost_{Network\_Small\_Diameter} = 4945400\ DKK$$

At 300 Pa/m

$Length_{Reused} := 3629\ m$

$Length_{OnePipe} := Length_{Reused} = 3629\ m$

$Length_{TwoPipes} := Length_{Network} - Length_{Reused} = 1341\ m$

$Cost_{Network\_Small\_Diameter} := Lbm_{OnePipe} \cdot Length_{OnePipe} + Lbm_{TwoPipes} \cdot Length_{TwoPipes}$

$Cost_{Network\_Small\_Diameter} = 4367240\ DKK$

The stretches of the gas network, where the existing gas are too close to the drinkingwater pipes, are removed from the reusable network.

For 200 Pa/m

$Length_{Reused} := 2215\ m$

$Length_{OnePipe} := Length_{Reused} = 2215\ m$

$Length_{TwoPipes} := Length_{Network} - Length_{Reused} = 2755\ m$

$Cost_{Network\_Small\_Diameter} := Lbm_{OnePipe} \cdot Length_{OnePipe} + Lbm_{TwoPipes} \cdot Length_{TwoPipes}$

$Cost_{Network\_Small\_Diameter} = 4989400\ DKK$

For 300 Pa/m

$Length_{Reused} := 3037\ m$

$Length_{OnePipe} := Length_{Reused} = 3037\ m$

$Length_{TwoPipes} := Length_{Network} - Length_{Reused} = 1933\ m$

$Cost_{Network\_Small\_Diameter} := Lbm_{OnePipe} \cdot Length_{OnePipe} + Lbm_{TwoPipes} \cdot Length_{TwoPipes}$

$Cost_{Network\_Small\_Diameter} = 4627720\ DKK$

Savings

$$\left(1 - \frac{4989400\ DKK}{5964000\ DKK}\right) \cdot 100 = 16.341$$

$5964000\ DKK - 4989400\ DKK = 974600\ DKK$

Assessment of gas pipe reuse for termonet in Rårup

Appendix F

Students:

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Supervisor:

Carsten Nielsen	**CARN**

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DD= Directional drilling

Unpaved: Includes leveling, delivery, laying pipes in the trench, DOES NOT INCLUDE EXCAVATION

Ø	Length	Price
32(stick)		
40(stick)		
50(stick)		
50		
63	2574.6	
75		
90	728.5	
110		
125	1288	
160	536.6	
200		
PE80	PN 2.5	

	Materials per m	**Job cost per m**	**Ventil cost (stk)**	**Job cost Ventil (stk)**	**Anboring(stk)**	**Job cost Anboring (Stk)**	**DD, Materials cost, per 50m**	**DD, Job cost, per 50m**	**DD, equipment fee, per 50m**
32(stick)	12	23	3016	499					
40(stick)	19	23	3111	499					
50(stick)	31	32	3330	499					
50	22	42			1854	287			
63	35	43			2472	287			
75	51	65	7726	999	2566	298			
90	66	78	7700	1074	2566	319	6706	17533	1373
110	88	80			2566	340	6919	18274	1373
125	107	85							
160	162	100			2932	383	7251	21448	1373
200	246	173			3163	478	12193	28203	1716

Network	4970
Price per m	522

NORTH

Ø	Length	Price	Stk
32(stick)			
40(stick)			
50(stick)			
32	118	60444.32	
40	0		
50	0		
63	71	36369.04	
75	763	390839.1	
90	1034	529656.2	
110			
160	376	226141.4	
SUM	2362	**1243450**	

SOUTH

Ø	Length	Price	Stk
32(stick)			
40(stick)			
50(stick)			
32			
40	71	36369.04	
50	150	76836	
63	805	412353.2	
75			
90	1200	614688	
110	262	139205.8	
160	120	72172.8	
	2608	1351625	

	DD/ per m
90	512.24
110	531.32
160	601.44

Length of one pipe=r Length of two pipes (network-reused)

	Fits diameter	Fits diameter and 1m spacing
200 Pa/m	2315	2215
300 Pa/m	3629	3307
COSTS		
AT 200 Pa/m	3980250	4032450
AT 300 Pa/m	3294342	3462426